Progress in SDUV-FEL and Development of X-Ray FELs in Shanghai

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Outlines

- Introduction to SDUV-FEL;
- Progress of SDUV-FEL experiments;
- Plans and R&Ds of X-Ray FELs Development;
- Summary.

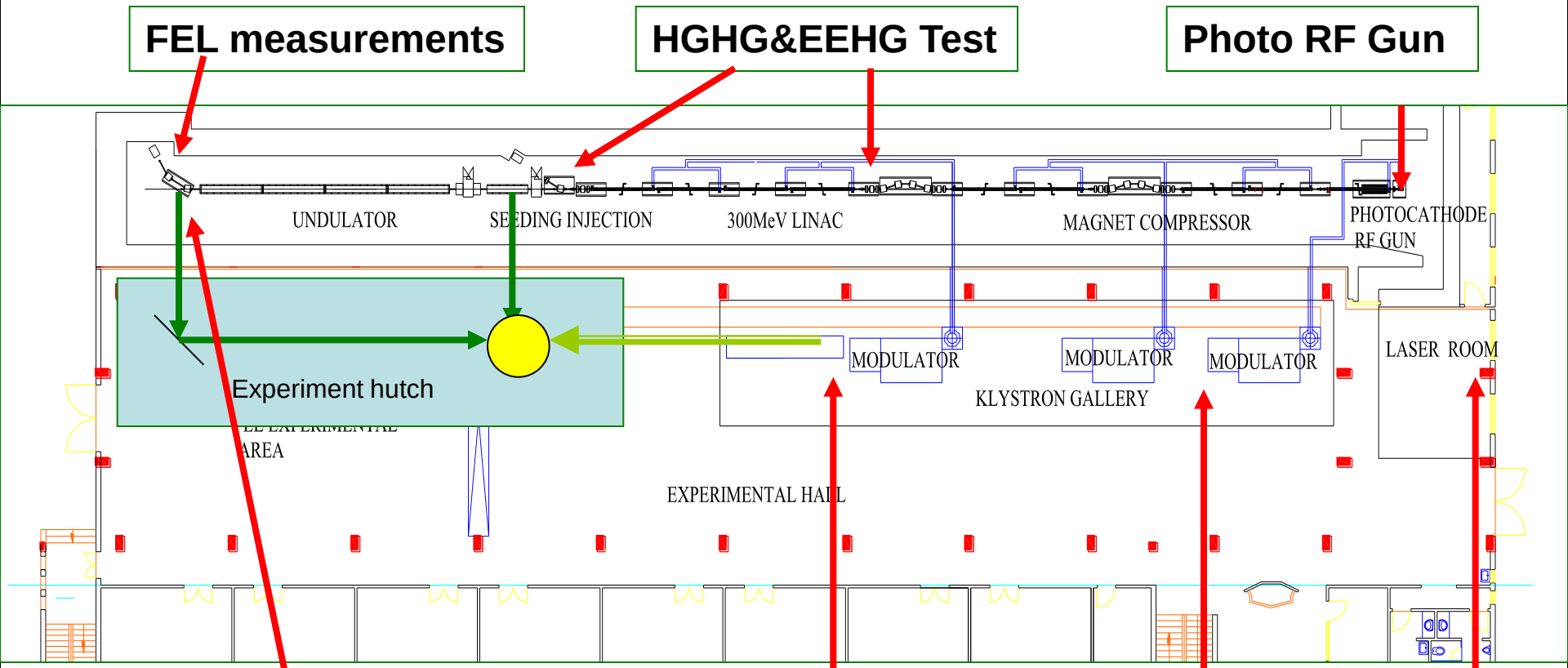
Introduction to SDUV-FEL

SDUV-FEL Program

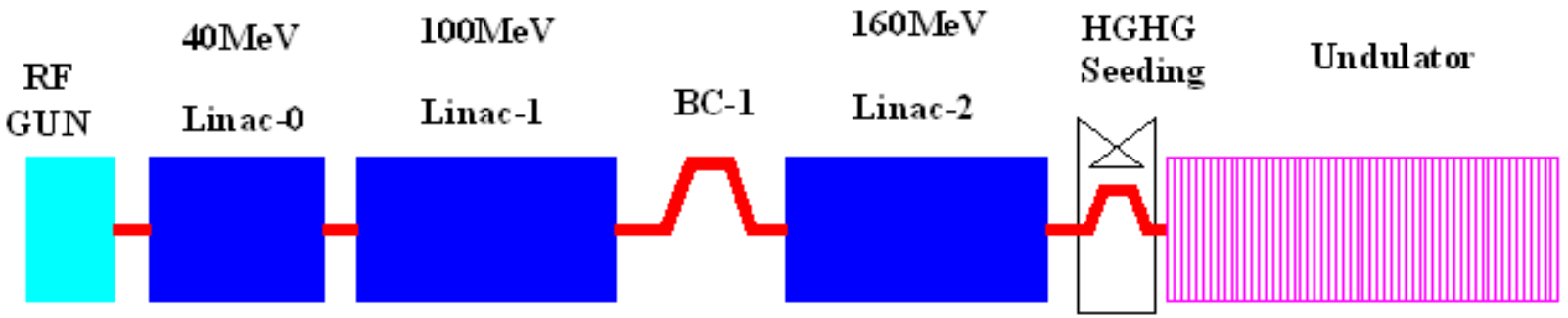
- Shanghai Deep-Ultraviolet FEL (SDUV-FEL) started as an HGHG FEL test setup, adding second modulator for Echo (EEHG) studies since 2009;
- Funded partially by
  - Chinese Academy of Sciences/CAS
  - Ministry of Science and Technology of China/MOST
  - Chinese Natural Science Foundation of /NSFC
- Collaborating institutes and universities include USTC, IHEP, THUB and SINAP;
- As a test bed for the key technologies for XFELs.

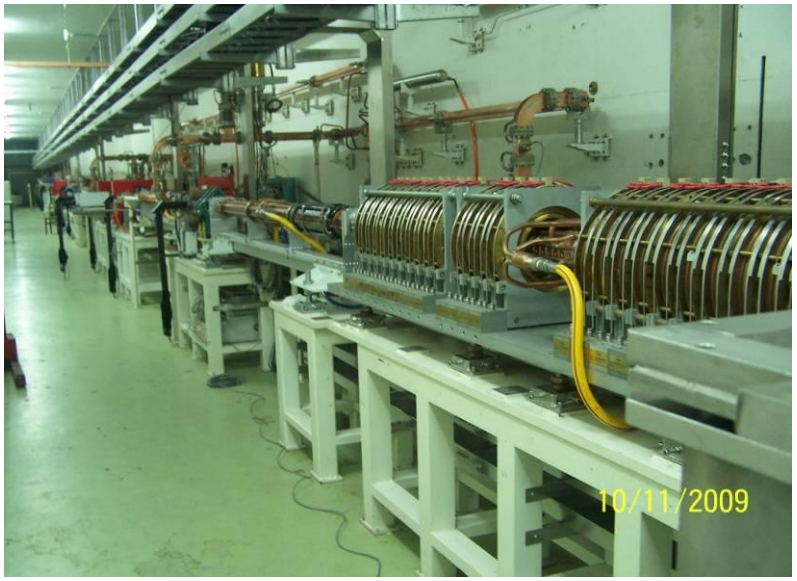

SDUV-FEL Experiment Hall

SDUV-FEL Layout



SDUV-FEL Facility

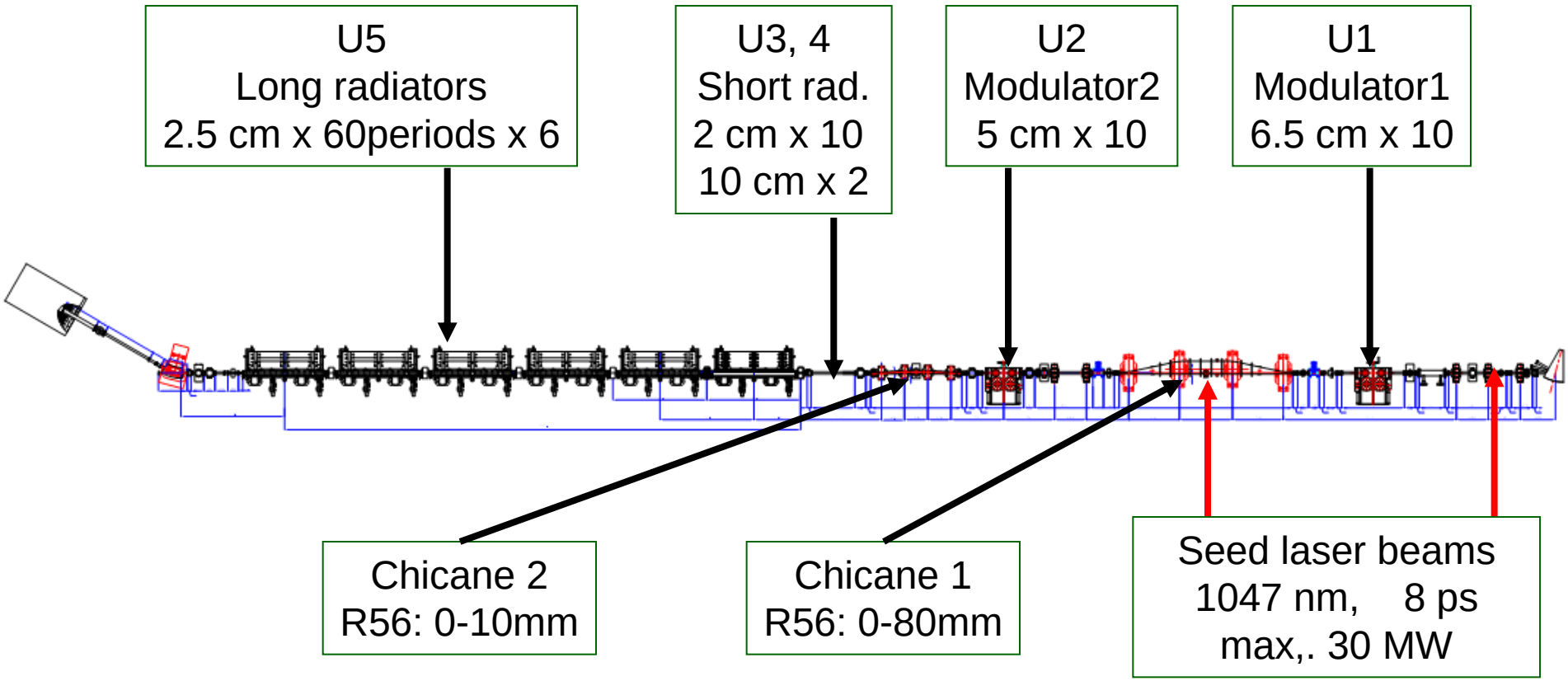


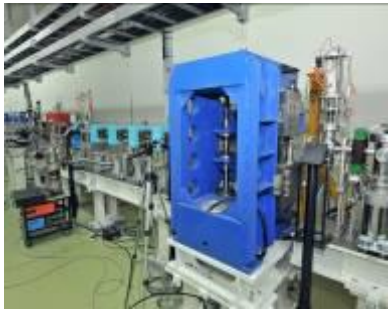
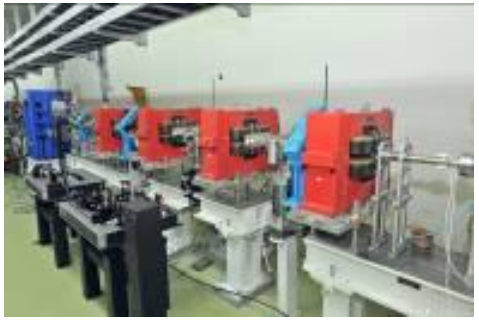


Main Parameters of SDUV-FEL

Beam energy	100-150MeV
Beam energy spread (projected)	<0.03%
Normalized emittance	4~5mm-mrad
Bunch Length (rms)	2~8ps
Bunch charge	100~300pC
Seed laser wavelength	1047nm
Seed laser pulse length	8ps
Seed laser Power	0~15MW

SDUV-FEL Test Facility




Seed1

Radiator

Mod2

DS2

EMU100
PMU20

DS1

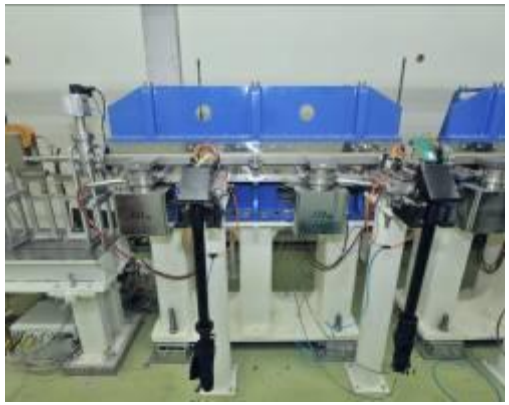
Seed2

Mod1

Linac
Exit

ODS2

ODS1



ODS=Optical Diagnostics Station

Progress of SDUV-FEL Experiments

Preliminary Experimental Results

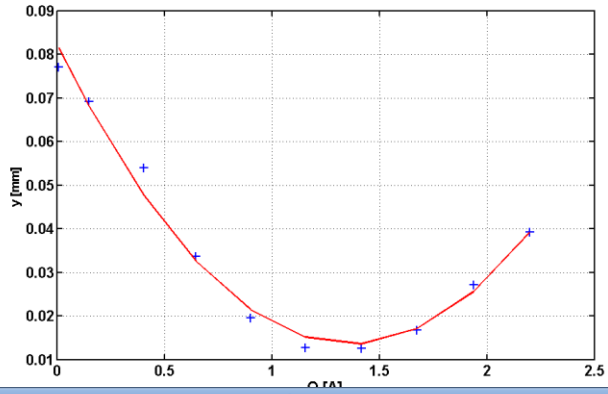
- Photo injector and linac commissioning and performance optimization;
- SASE experiments: exponential growth, spectra;
- HGHG experiments: bunching characteristics studies;
- ECHO experiments: proof-of-principle experiment of EEHG, first observation of the echo signal.

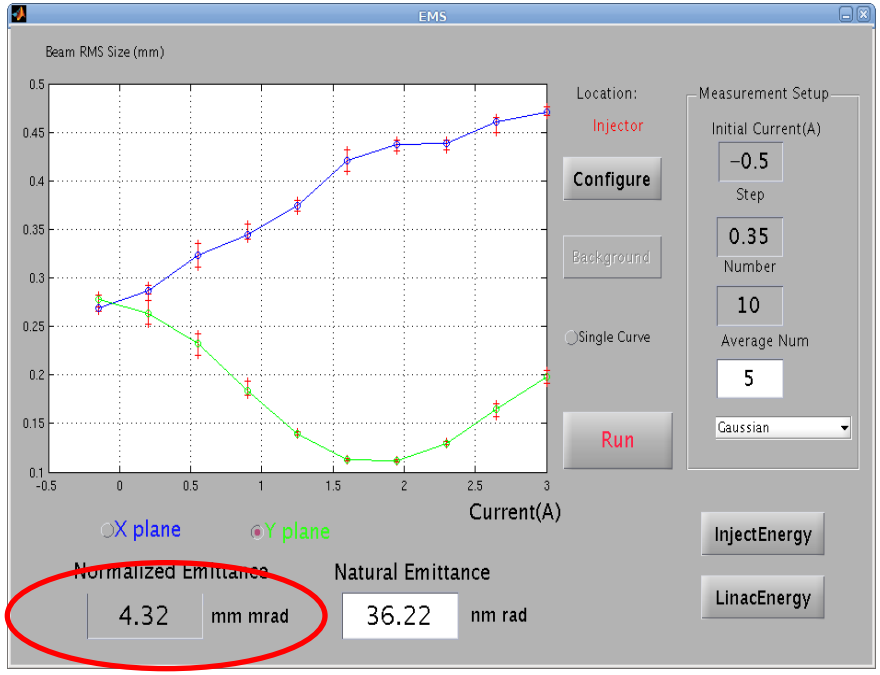
Milestones of SDUV-FEL experiments

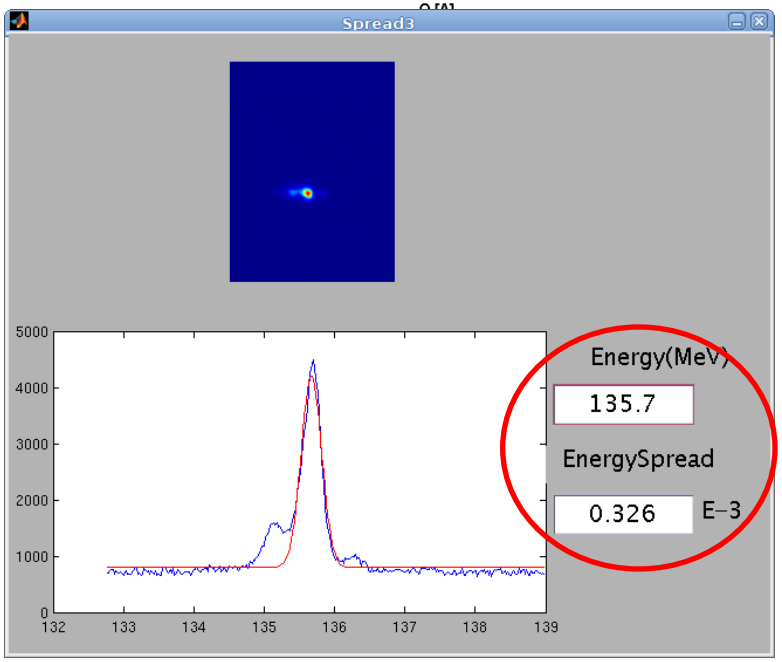
- 2009.04-08: Linac commissioning
- 2009.09-12: SASE experiment
- 2010.01-03: Seeded FEL Installations
- 2010.05: Seeded FEL experiments start
- 2010.05.17: HGHG signal
- 2010.05.22: First Echo signal (‘double-peak’)
- 2010.07-08: Install. for high harmonics EEHG

Linac Commissioning Results

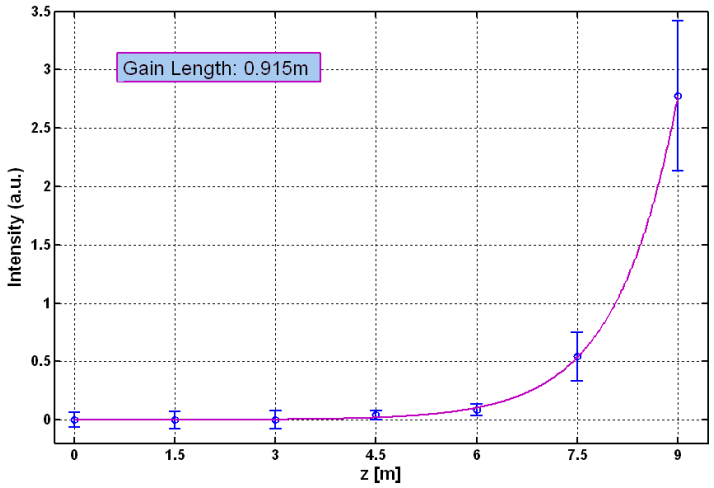
- Energy: 100-150 MeV
- Energy spread: <0.03%
- Emittance: 4-5 mm-mrad

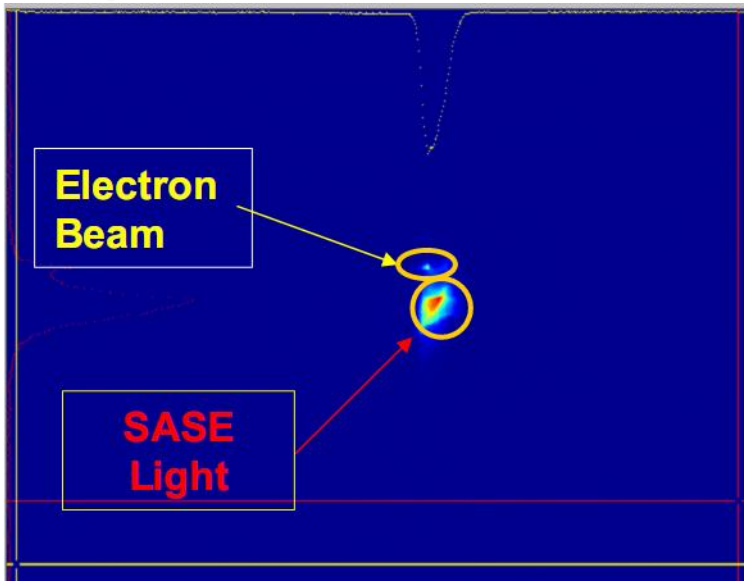


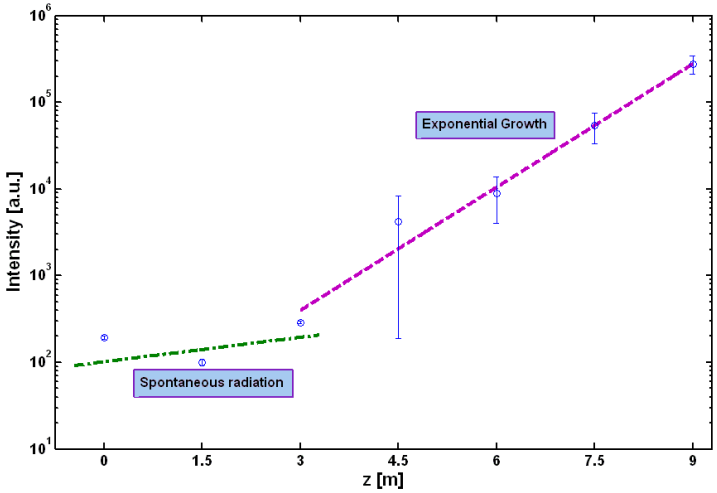


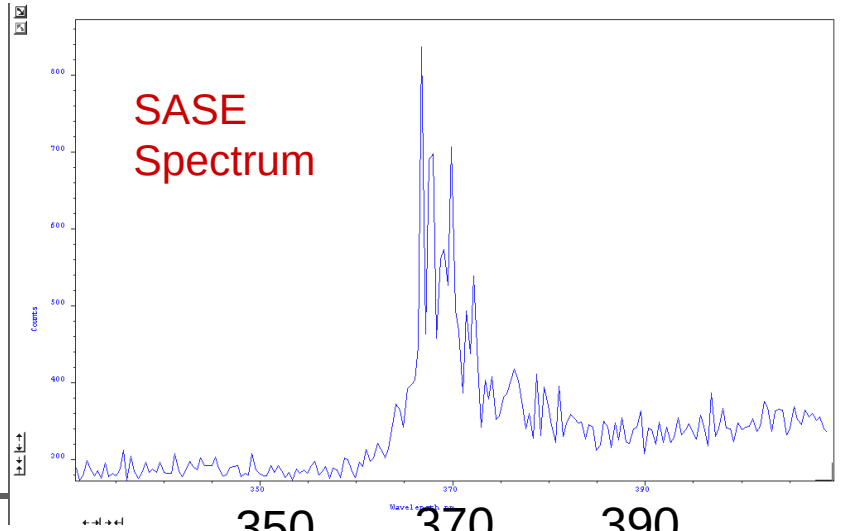


SASE Experimental Results (linac + 9m undulator)



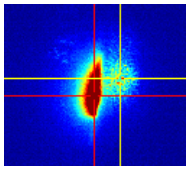


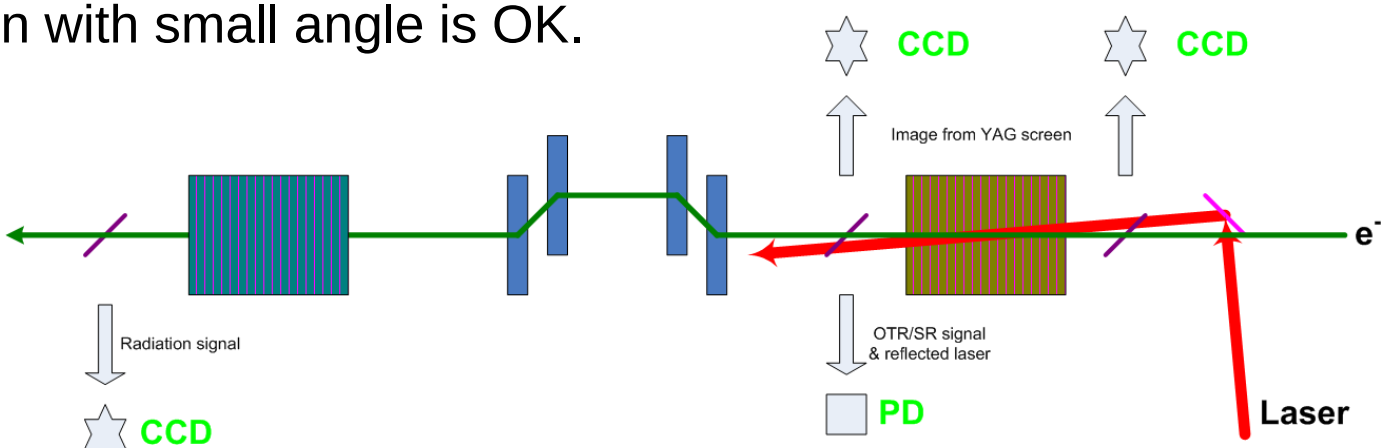


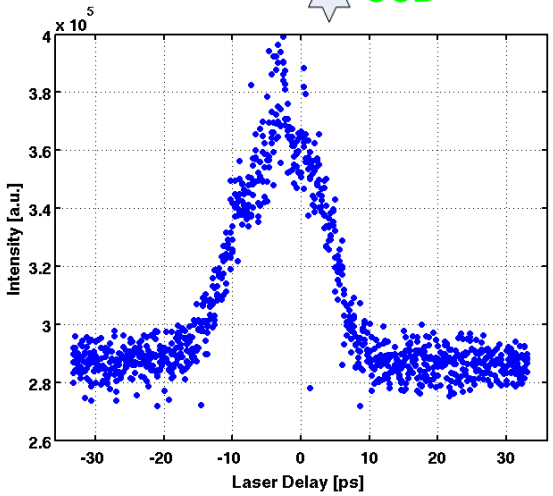


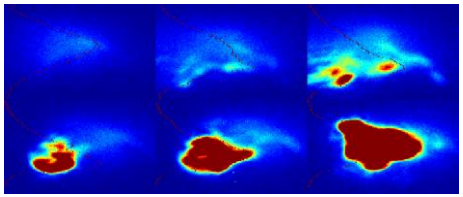
Overlap of laser and electron beam

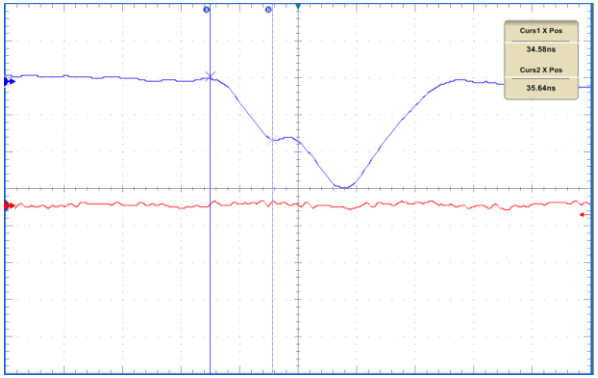
- Laser pulse: 8ps (FWHM)
- Electron beam: ~10ps
- Timing jitter is NOT an issue
- Injection with small angle is OK.



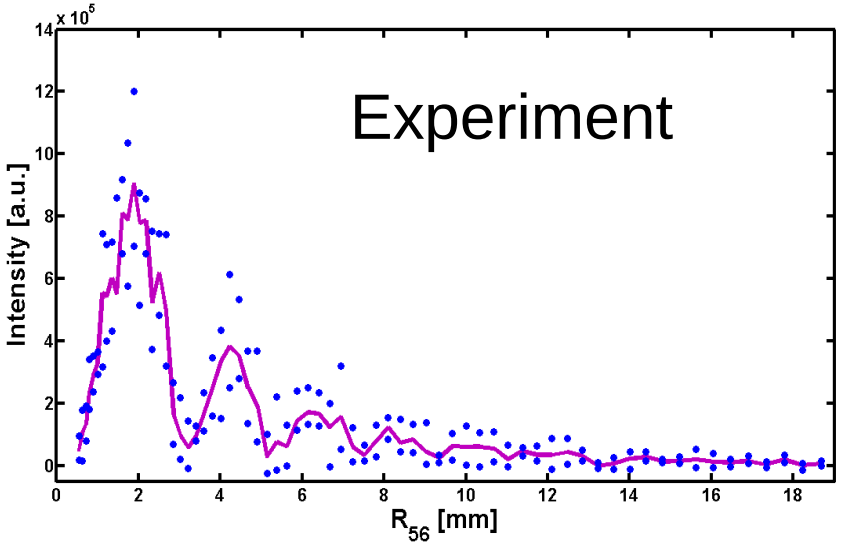


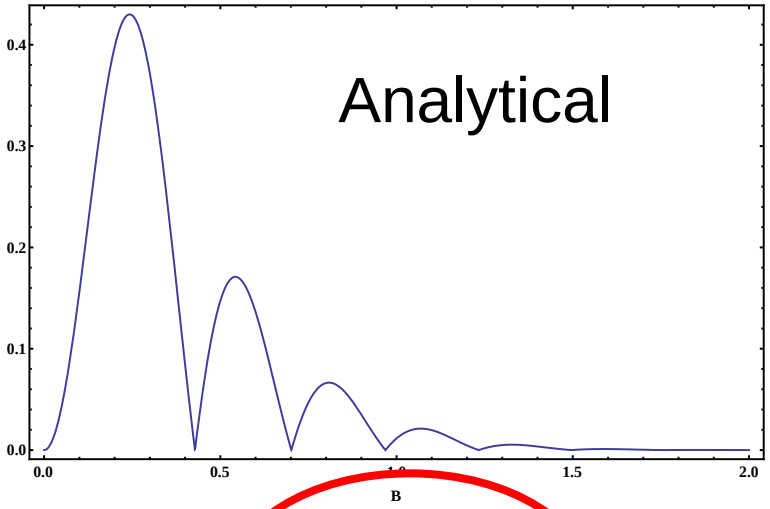






Coherent undulator radiation with HGHG bunching
(2nd harmonic)





$$2|b_k| = 2|J_k(ABk)|e^{-\frac{1}{2}B^2k^2}$$

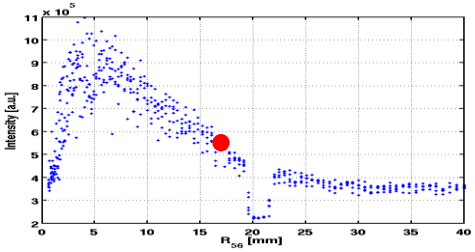
Turn on Mod1, use modulator2 as a radiator.

Scan R56_1 we get Bessel function, A1 should be big enough.

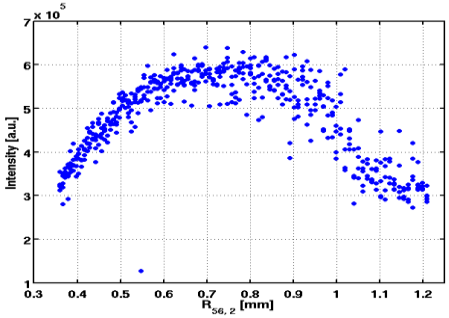
First ECHO Signal

measured on May 22, 2010, reported on May 26 at IPAC2010

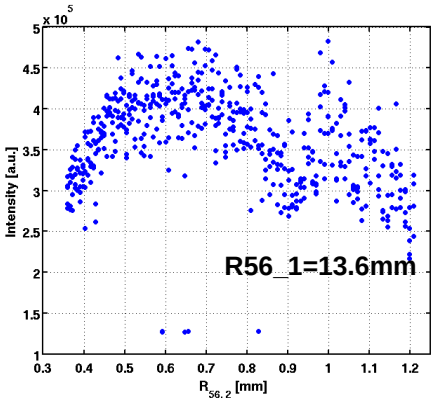
First Stage HGHG



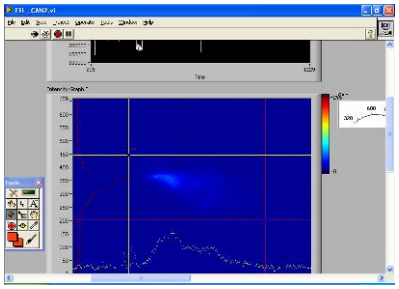
Second Stage HGHG



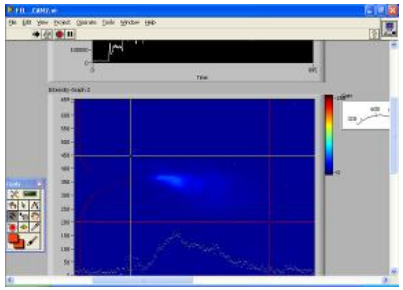
EEHG Setup



HGHG bunching smeared out at ECHO condition

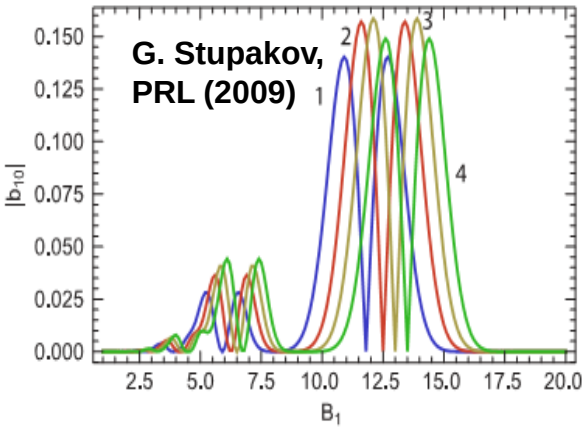


Seed Laser-1 OFF

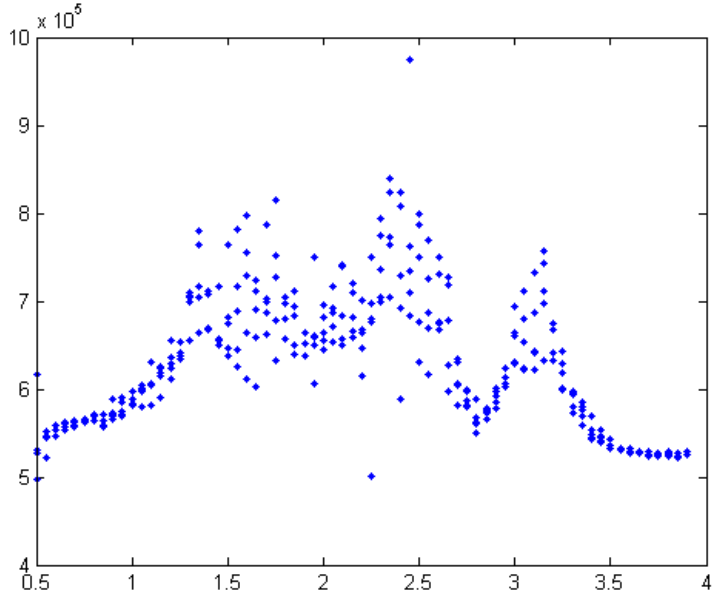


Seed Laser1 ON

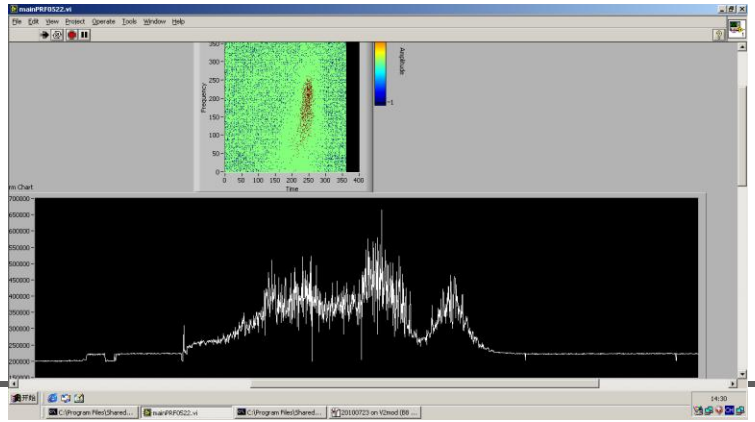
"Double peaks" was observed with EEHG setup, which agrees with EEHG theory.

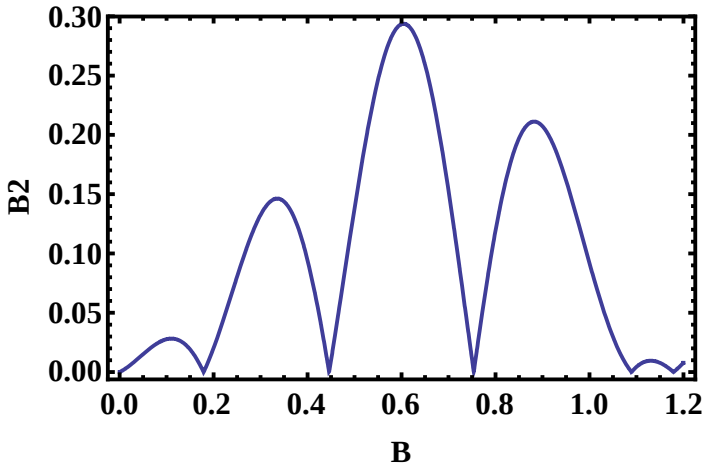


EEHG bunching dependence on R56_2 (B2)
(2nd harmonic)



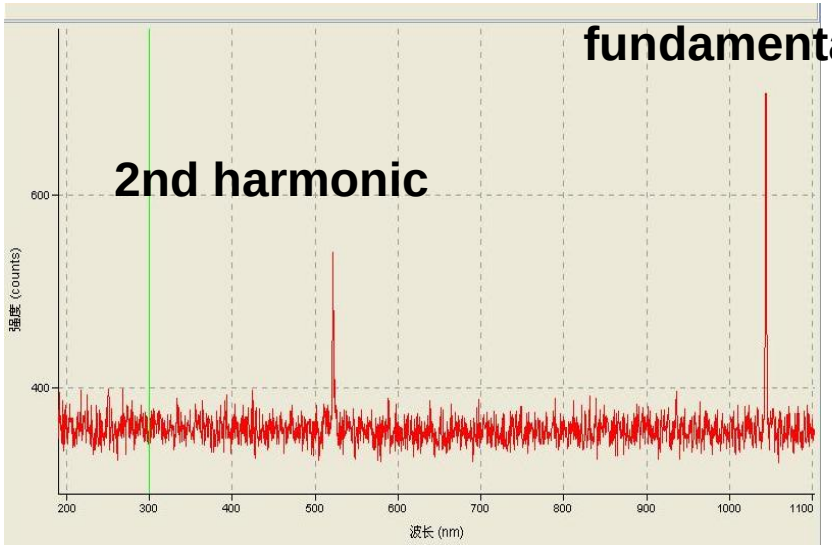
In some situations, multi-peak were observed and agree well with theoretical expectations





A1=6，A2=3，B1=1.5

Coherent undulator radiation with EEHG bunching, spectral measurement



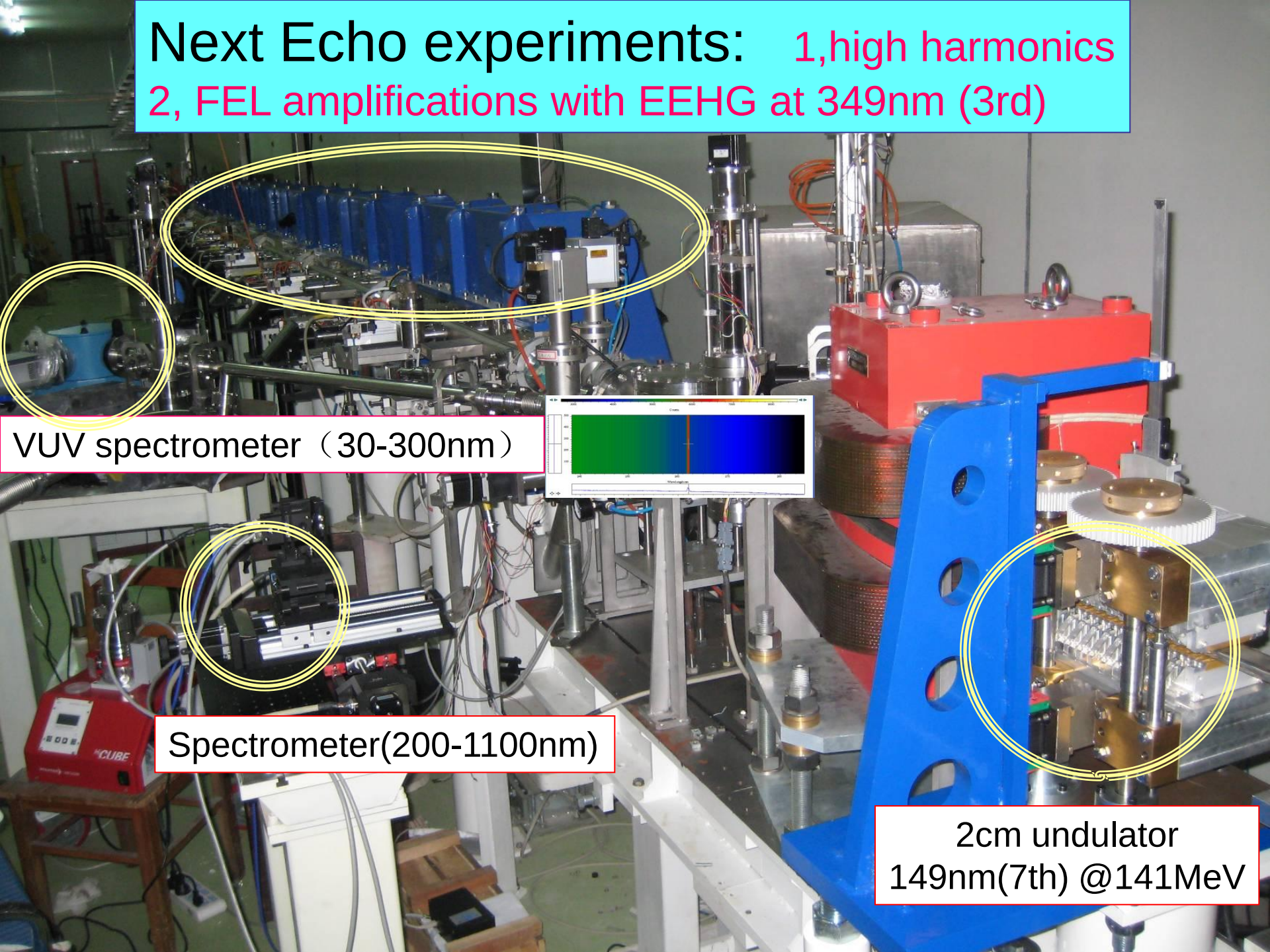
The 2nd harmonic was chosen mainly for diagnostics reason.

Fundamental and other harmonics were filtered out.

EEHG 2nd harmonic radiation observed with spectrometer.

Next Echo experiments: 1,high harmonics

2, FEL amplifications with EEHG at 349nm (3rd)

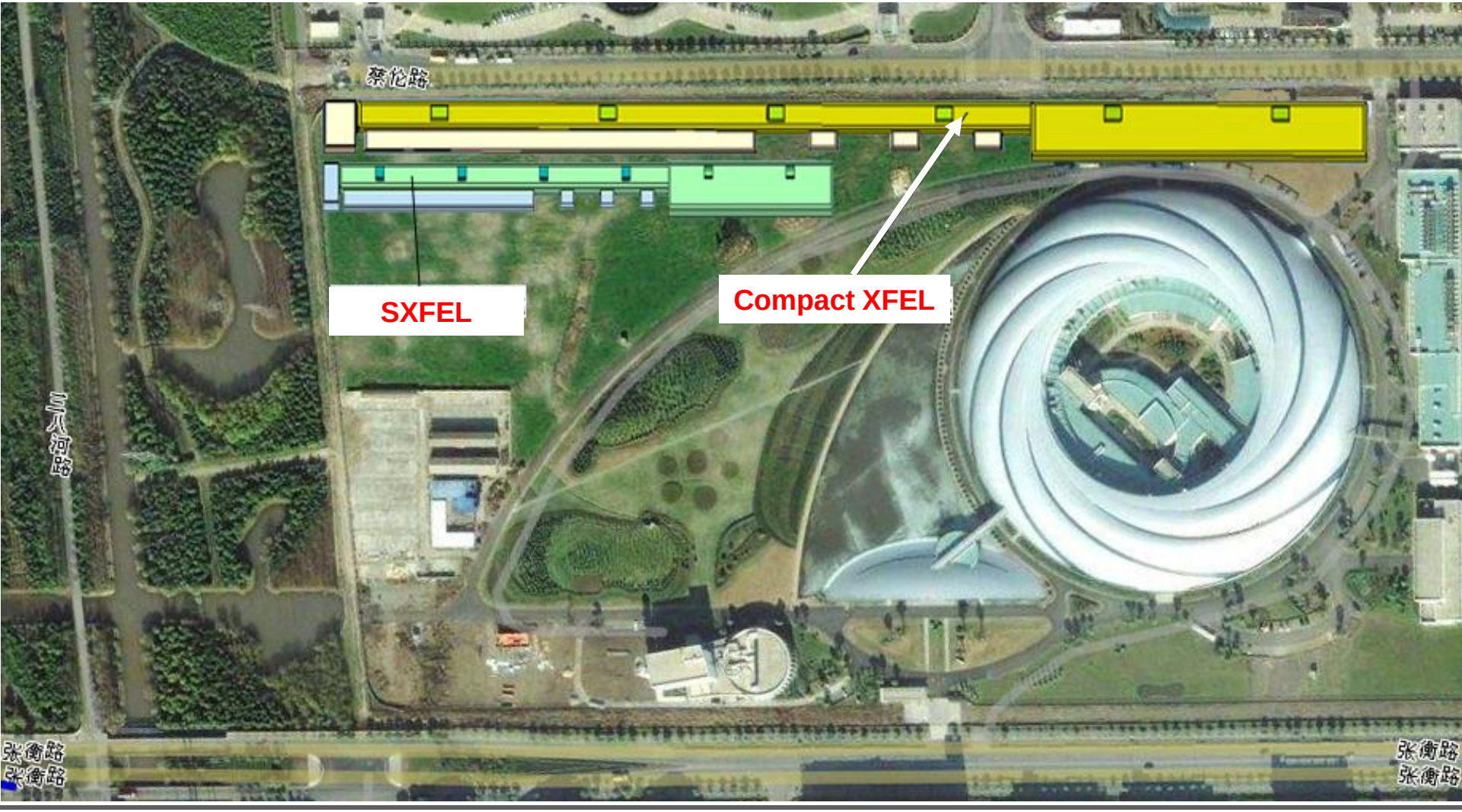


Plans and R&Ds for XFELs in Shanghai

Plans and R&Ds for development XFELs

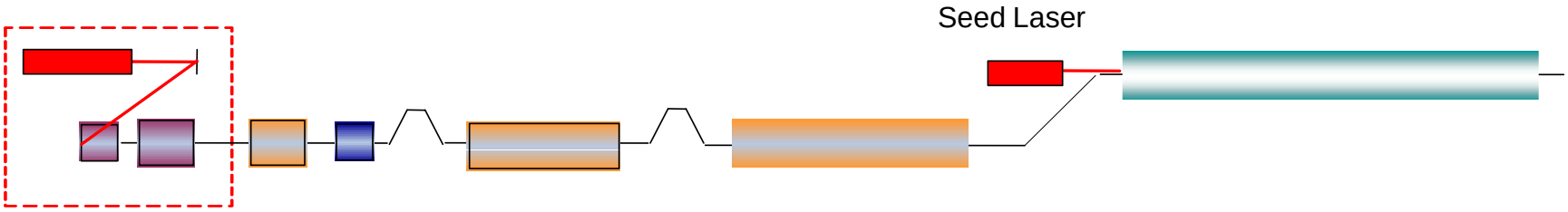
- A soft XFEL test facility based on 0.84 GeV was proposed to test cascaded HGHG scheme, the project is in the approval procedure of the central government;
- A design study on a 0.1 nm compact X-ray FEL based on a 6.4GeV C-band linac, which is fit the available space in the SSRF campus, is being carried out;
- R&Ds of key technologies for XFELs are under way at SINAP, including high gradient C-band accelerating structures, beam diagnostics and etc;

Layout of Shanghai XFELs

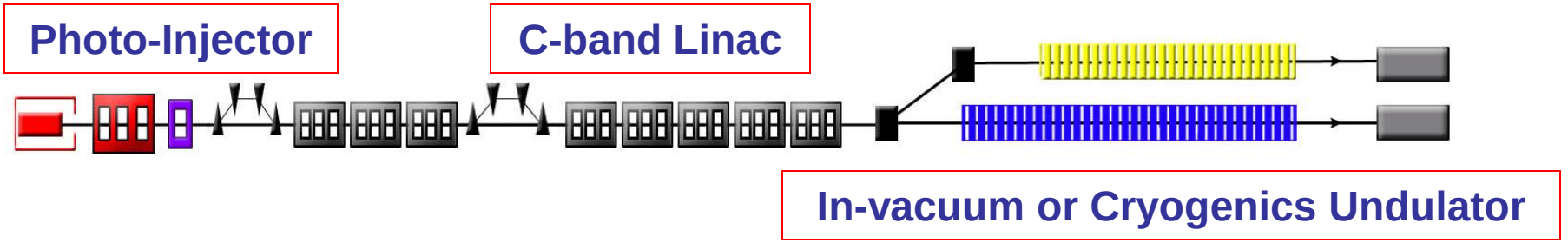


Shanghai XFELs

SXFEL: In the progress of approval



Compact Hard XFEL: Design study (R&D)



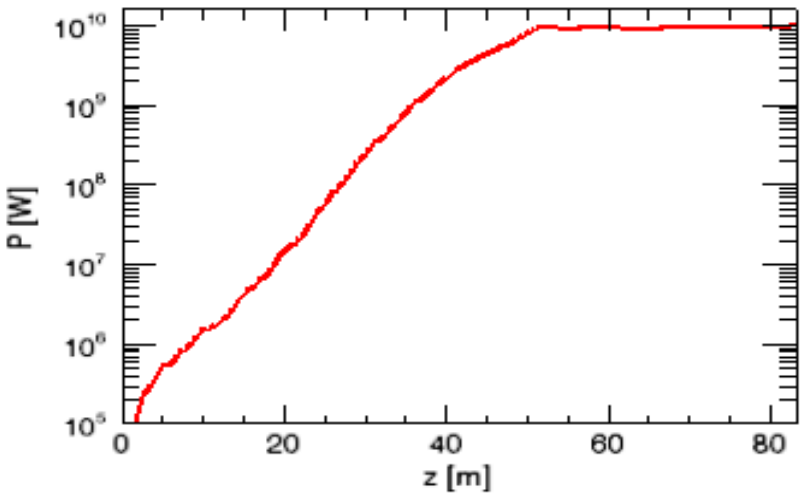
Main Parameters of SXFEL

Seed laser	λ_s=270nm， P_{max}=200MW, τ_s=100fs				
Electron parameter	E=0.84GeV，I_p=600A，ε_n=1.5~2.5 mm·mrad, δE/E=0.1% , τ=1.7ps, rep rate: 10 Hz				
	parameter	1st stage		2nd stage	
Undulator	λ_u (cm）	5.8	3.8	3.8	2.5
	g (cm)	~1.2	~1.1	~1.1	~1.0
	L_U (m)	1.0	6.0	1.0	18.0
Disp. sec	$d\psi/d\gamma$	2.1		5.9	
FEL parameter	λ (nm)	270	45	45	9
	L_G (m)	0.78	0.88	0.88	1.32
	P (MW)		≥100		≥100
	τ_{FEL} (fs)	100		100	

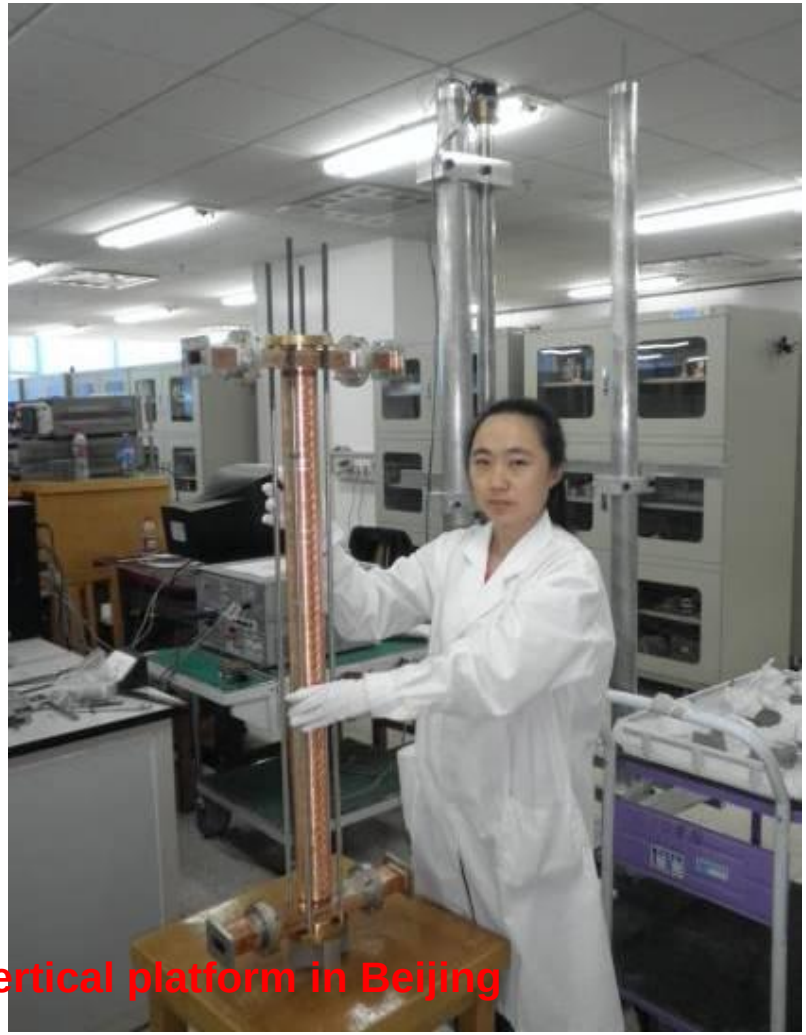
Parameters of Compact XFEL

Electron beam parameters	
Energy/GeV	6.4
Peak current/kA	3
Bunch charge/pC	250
Normalized slice emittance/mm-mrad	0.4
RMS slice energy spread	0.01%
Full bunch length/fs	100
Undulator parameters	
Period/cm	1.6
Segment length/m	4.8
Full undulator length	70
Peak undulator field/T	0.93
K	1.4
Gap/mm	6
Average beta function/m	20

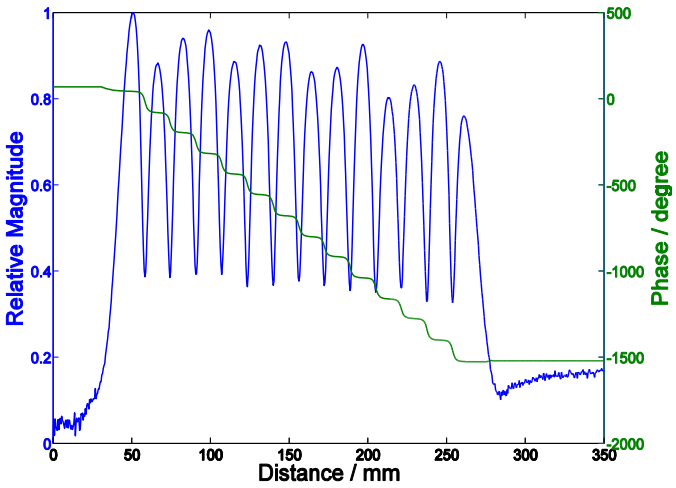
FEL parameters	
Radiation wavelength/nm	0.1
ρ	3.41e-4
Peak coherent power/GW	10
Peak brightness/*	2e33
Pulse repetition rate (Max.)/Hz	60
3D gain length/m	2.156
Saturation length/m	50



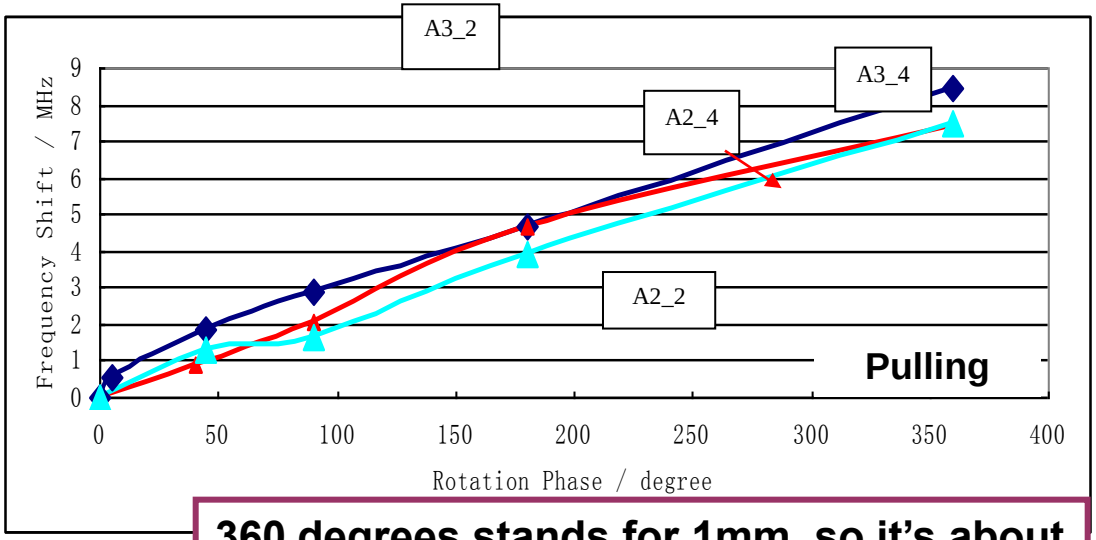
R&D Model of C-Band Accelerating Structure



Structure Tuning Results

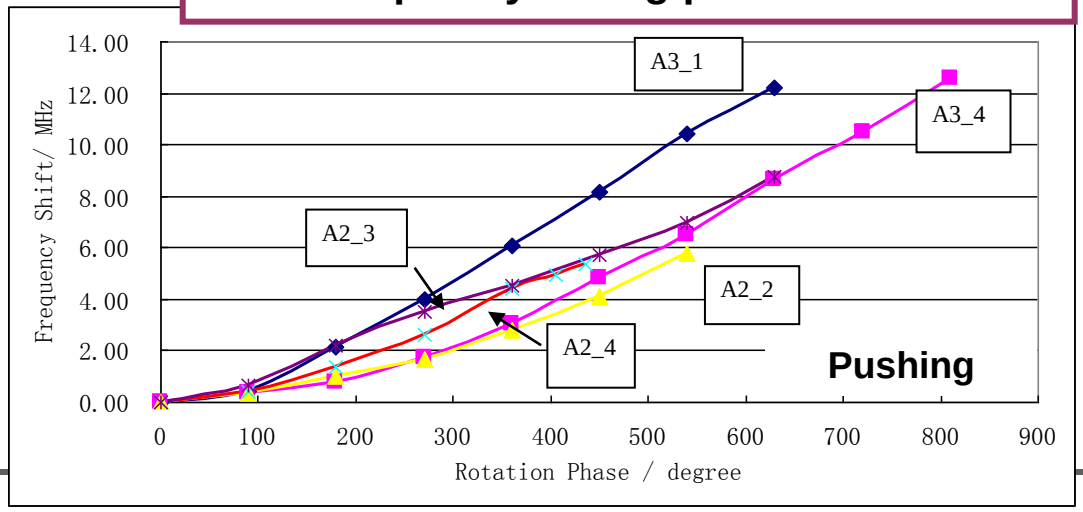


After tuning SWR is about 1.1



360 degrees stands for 1mm, so it's about 7MHz frequency tuning per 1 mm

According to measurement, resonant frequency is about 5708MHz, so 2 tuning holes for each cell are enough for the tuning target 5712MHz



Summary

- SASE, HGHG and EEHG experiments were carried out at SDUV-FEL facility, the echo signal was observed;
- Efforts are being made to observe the higher harmonic radiation of the EEHG and the FEL amplification with HGHG and EEHG;
- Design studies on the SXFEL test facility and the compact XFEL are being carried out, and R&Ds of the key technologies for XFELs under way in the meantime.

Acknowledgement

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Thanks for your attention !