Eliminating the microbunching-instability-induced sideband in a soft x-ray self-seeding free-electron laser

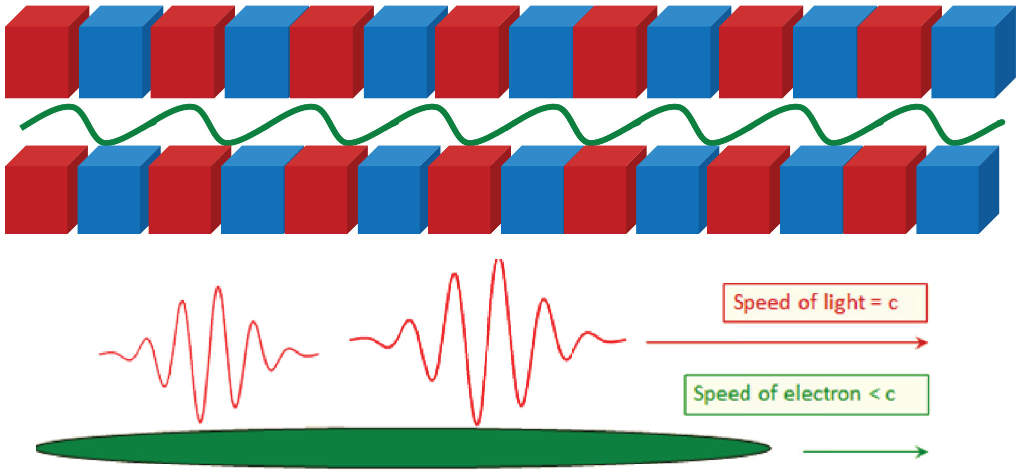
Kaiqing Zhang

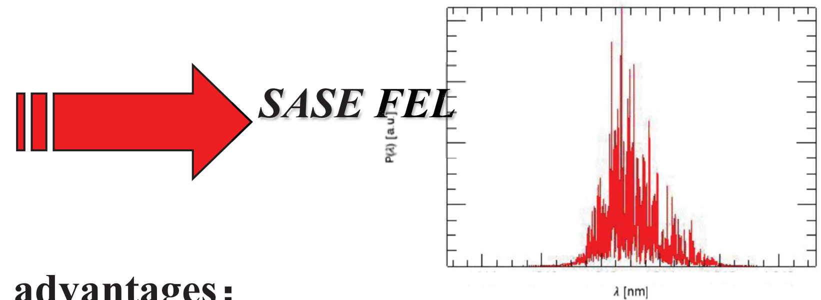
SINAP FEL

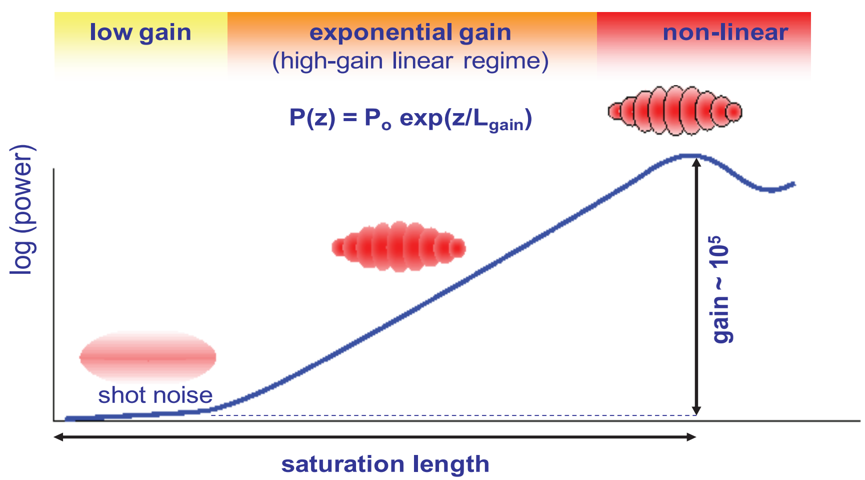
SINAP 中国科学院上海应用物理研究所
Shanghai Institute of Applied Physics, Chinese Academy of Sciences

OUTLINE

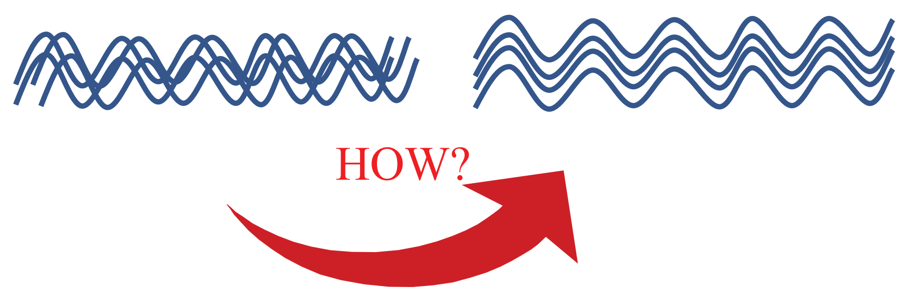
Self-amplified self-emission(SASE)







advantages:
High efficiency, high peak power, short wavelength, transverse coherence
Drawbacks:
-Bad longitudinal coherence
-Wide bandwidth
-Time jitter
-Wavelength jitter



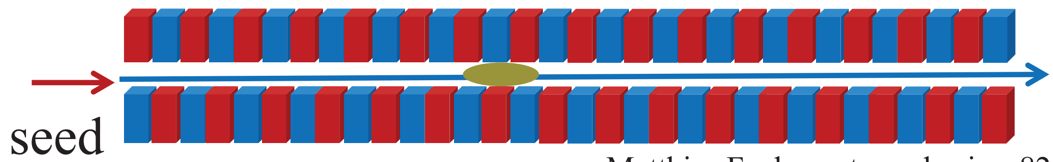
FEL is a self-organized process, it makes the electron beam from "random distribution" to "coherent distribution.

Peter Schmuser et al.,.2008 Springer 0081-3869
J. Andruszkow, PRL, VOLUME 85, NUMBER 18(2000)

Improve Longitudinal Coherence

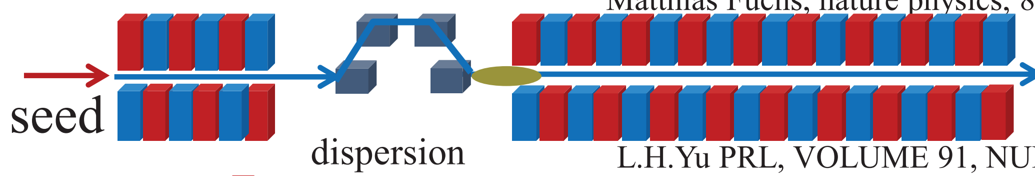
External laser seed:

- Direct Seeding



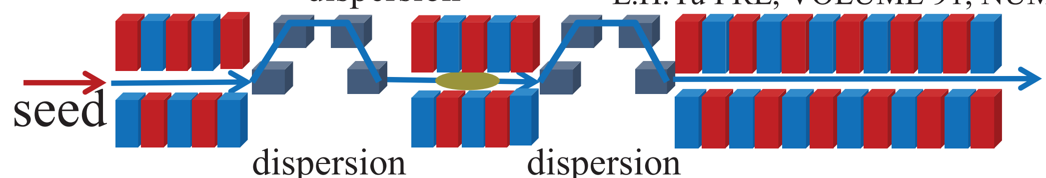
Matthias Fuchs, nature physics, 826-829

- HGHG



L.H.Yu PRL, VOLUME 91, NUMBER 7

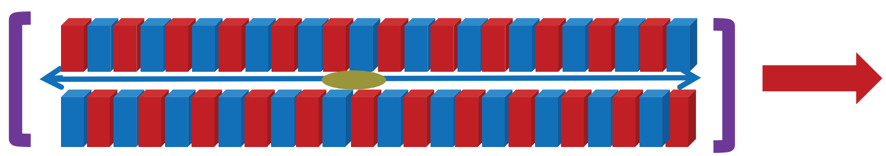
- EEHG



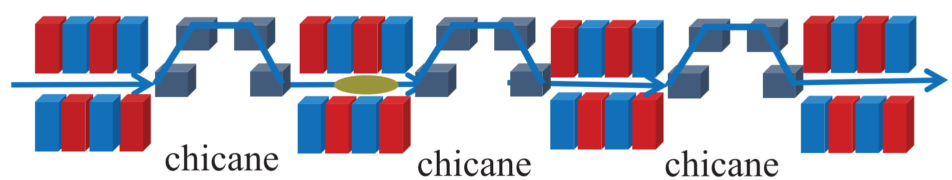
Z. T. Zhao, nature photonics,360-363

Coherence control:

- FEL Oscillator



- HBSASE
- eSASE
- pSASE



N. R. Thompsona, Physics Procedia (52 – 61)

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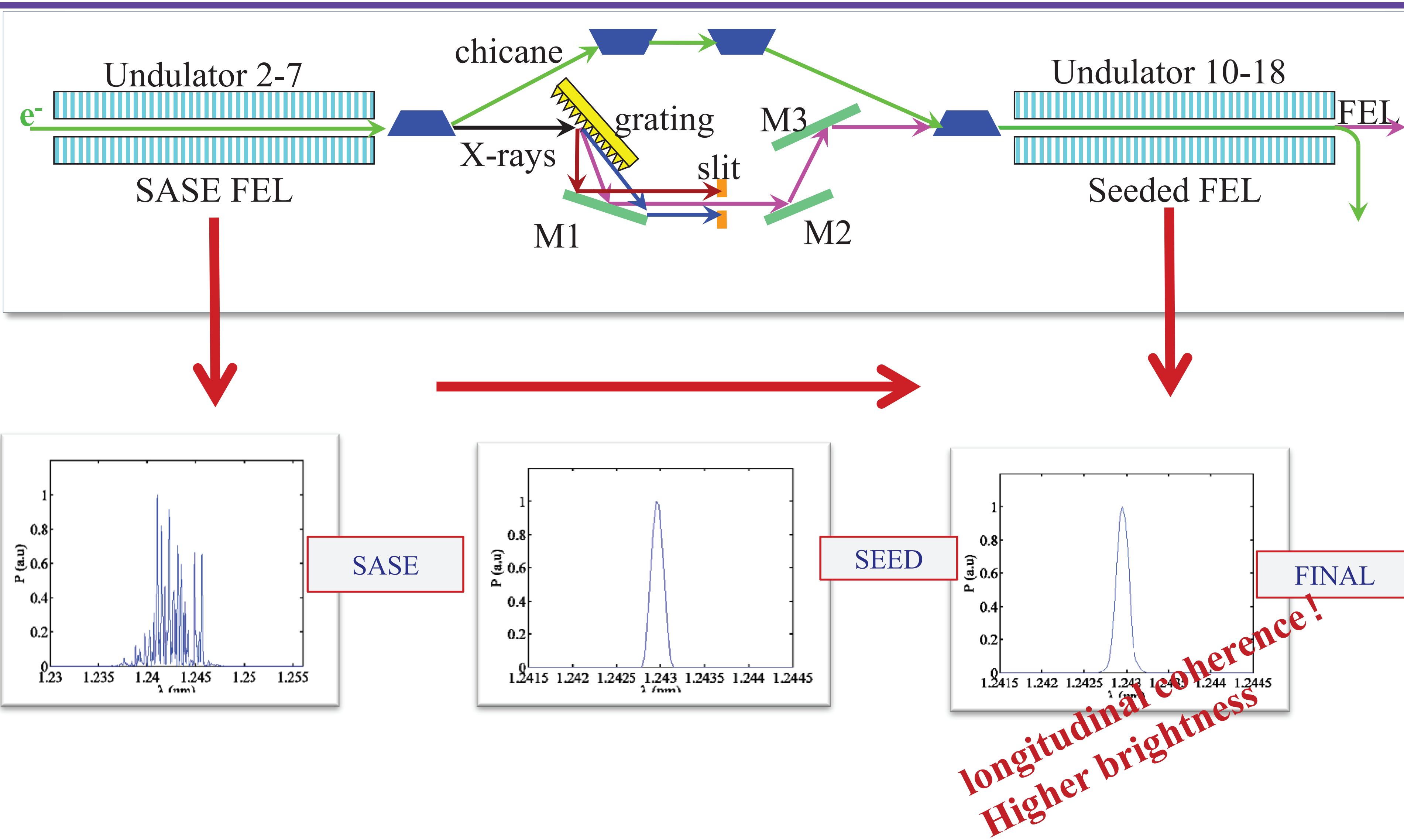
Self-seeding FEL



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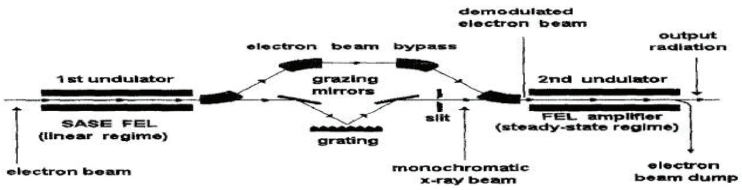
Kaiqing Zhang et al., in IPAC16, Busan, korean, MOPOW029.

Research status

1997

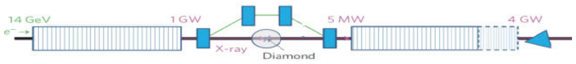
J. Feldhaus proposed self-seeding

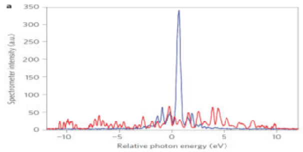
J. Feldhaus et al., Optics Comm., 140 (1997)



2012

LCLS hard-x-ray :

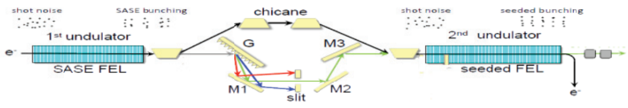


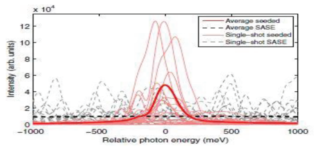


J. Amann et al., Nature photonics(2012)

2014

LCLS soft-x-ray :

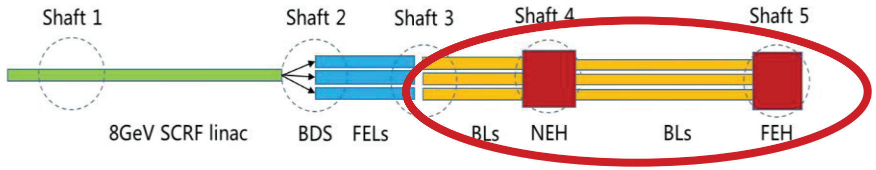




D. Ratner et al., PRL 114, 054801 (2015)

Problems in self-seeding：
Self-seeding schemes have been proved to be reliable methods for soft x-ray and hard x-ray FEL generation . However, the longitudinal coherence and stability still require further improvement.

Self-seeding in SINAP



SXFEL user facility
1.6 GeV, ~1nm
SASE-----self-seeding

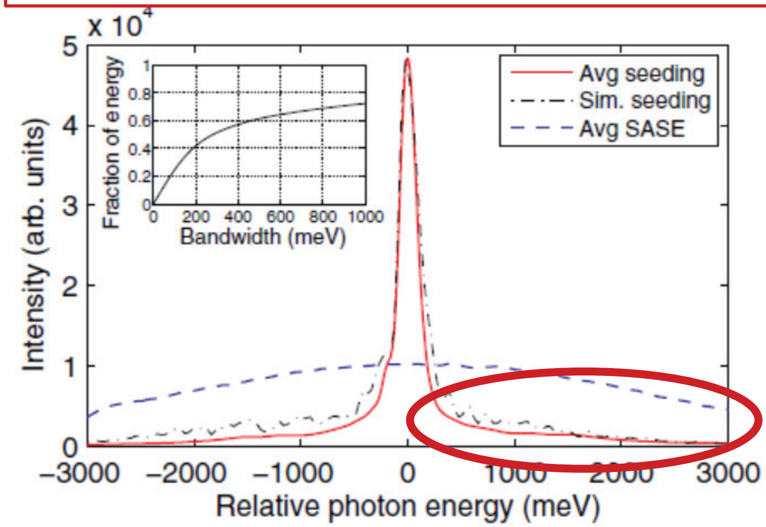
Soft x-ray self-seeding is one basic operation mode of SCLF, 0.4-3keV

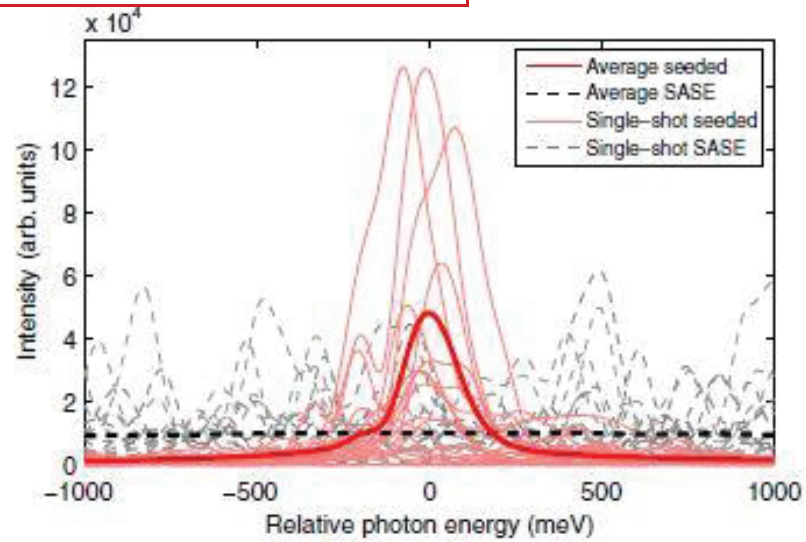
Lines: SASE(soft and hard x-ray self-seeding), External seed

Sideband in SXSSF

2014 LCLS soft-x-ray experiment :

Critical problem in soft x-ray self-seeding





Bandwidth： 0.15~%
SASE： 0.2%
Ideal condition：0.01%

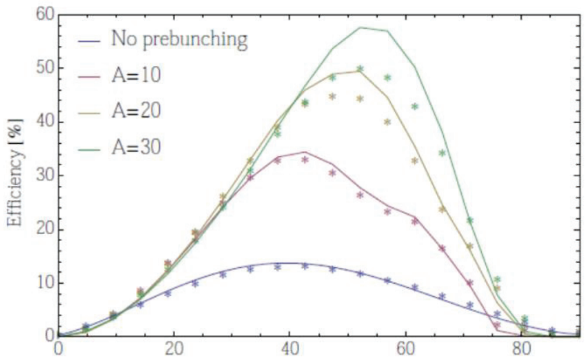
Peak power jitter：50%

D. Ratner et al., PRL 114, 054801 (2015)

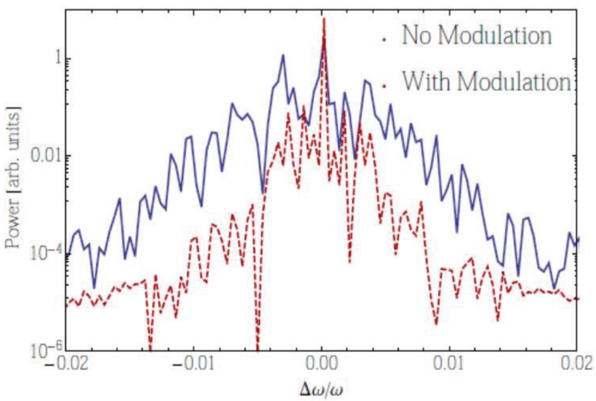
High efficiency TW FEL

High efficiency tapered FELs with a pre-bunched electron beam

C. Emma,[1] N. Sudar,[1] P. Musumeci,[1] A. Urbanowicz,[1] and C. Pellegrini[1,2]
[1] *University of California, Los Angeles, California 90095, USA*
[2] *SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA*
(Dated: September 5, 2017)



of the system. The most deleterious effects for a high gain, high efficiency FEL are due to the synchrotron sideband instability. The sideband instability results from



1. Self-seeding can be used to generate TW FEL radiation if tapering adequately the undulator after saturation.
2. Sideband is the main barrier to enhance the efficiency and achieve TW FEL radiation.

Prediction of sideband

PHYSICAL REVIEW ACCELERATORS AND BEAMS **19**, 050701 (2016)

Microbunching-instability-induced sidebands in a seeded free-electron laser

Zhen Zhang,[1,2] Ryan Lindberg,[3] William M. Fawley,[1] Zhirong Huang,[1] Jacek Krzywinski,[1] Alberto Lutman,[1] Gabriel Marcus,[1] and Agostino Marinelli[1]

[1]*SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA*
[2]*Department of Engineering Physics, Tsinghua University, Beijing 100084, China*
[3]*Advanced Photon Source, Argonne National Laboratory, Argonne, Illinois 60439, USA*

(Received 18 February 2016; published 2 May 2016)

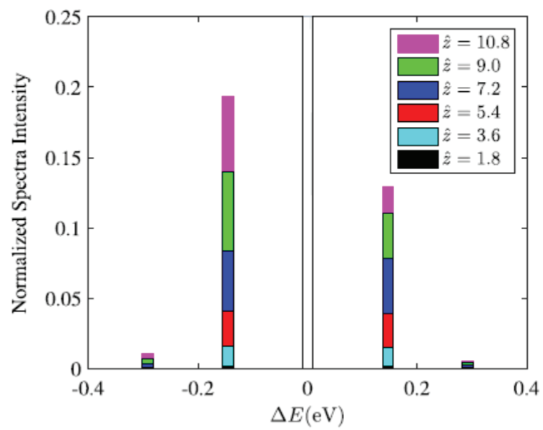
Prediction:
Sideband in SXSSF is mainly induced by michrobunching instability produced by LINAC

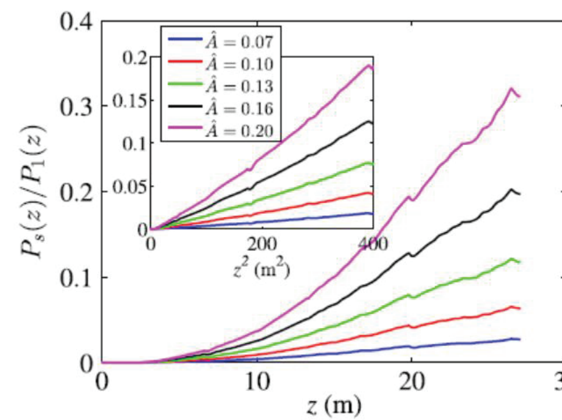
$$\frac{d^3 a_1}{d\hat{z}^3} \approx i a_1$$

$$\frac{d^3 a_s}{d\hat{z}^3} + i\frac{\Delta\nu}{2\rho}\frac{d^2 a_s}{d\hat{z}^2} \approx i\nu a_s + \nu^2 \hat{A} p_1$$

$$A(\xi) = A_m cos(k_m \xi)$$

$$\frac{P_s(\hat{z})}{P_1(\hat{z})} = \frac{\hat{A}^2}{9}\hat{z}^2 = \frac{4}{9}{A_0}^2{k_u}^2 z^2$$





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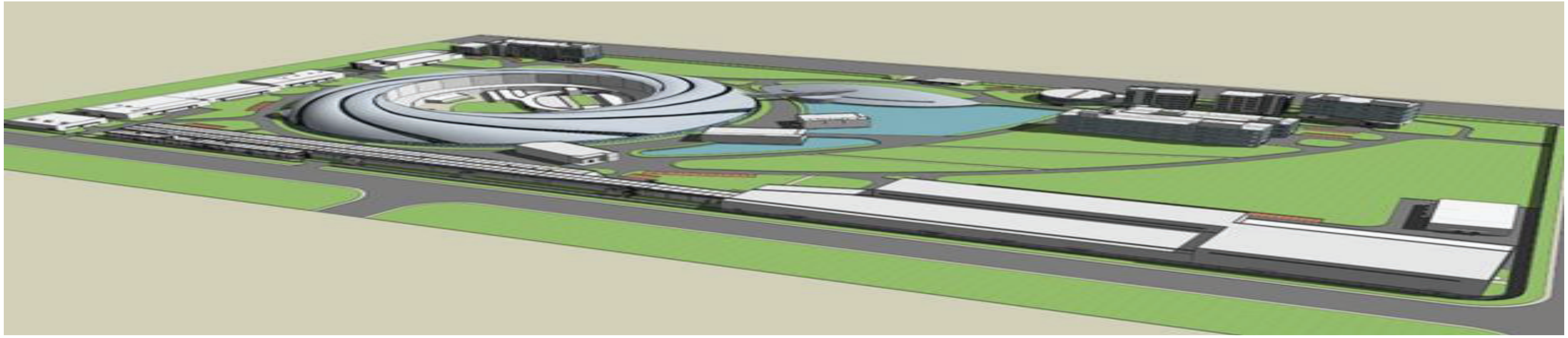
Z. Zhang et al., Physical Reviews Accelerators Beams 19 (2016) 050701.

Prediction verification of sideband

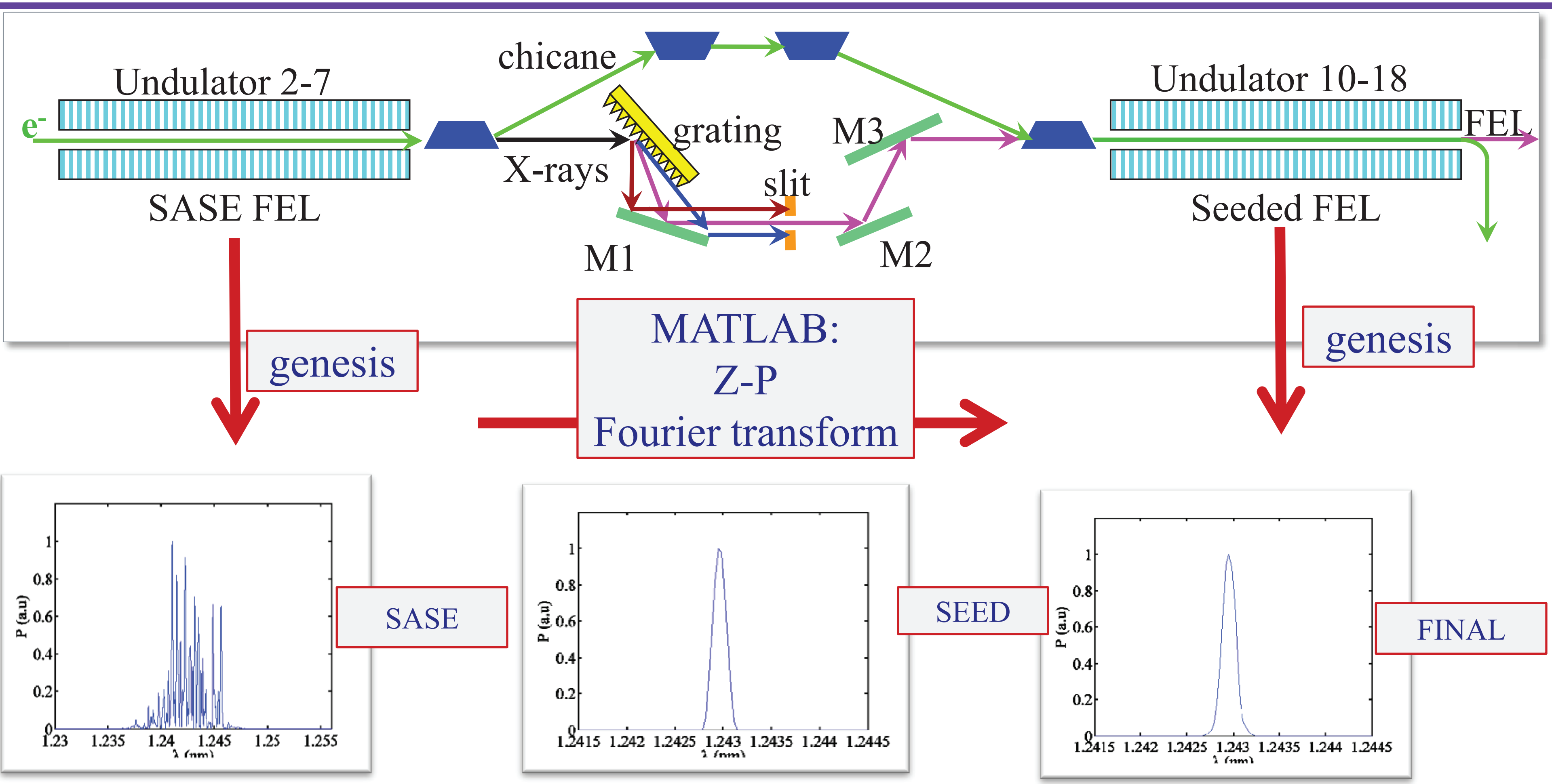
The simulation parameters are based on the SXFEL user facility

Main parameters for the simulations

Electron beam parameter	Value	Unit
Electron beam energy	1.6	GeV
Energy spread	0.01%	-
Peak current	1.5	kA
Bunch length	40	fs
Normalized emittance	0.45	mm-mrad
Mono. Central energy	1.243	keV
Mono. Resolution power	1/10000	-
Mono. Power Efficiency	0.03	-
Undulator period	0.0235	m
SASE undulator length	20	m
Seeded undulator length	20	m



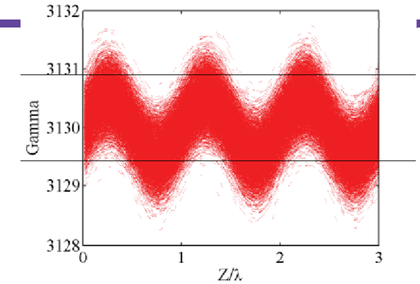
Self-seeding FEL simulation



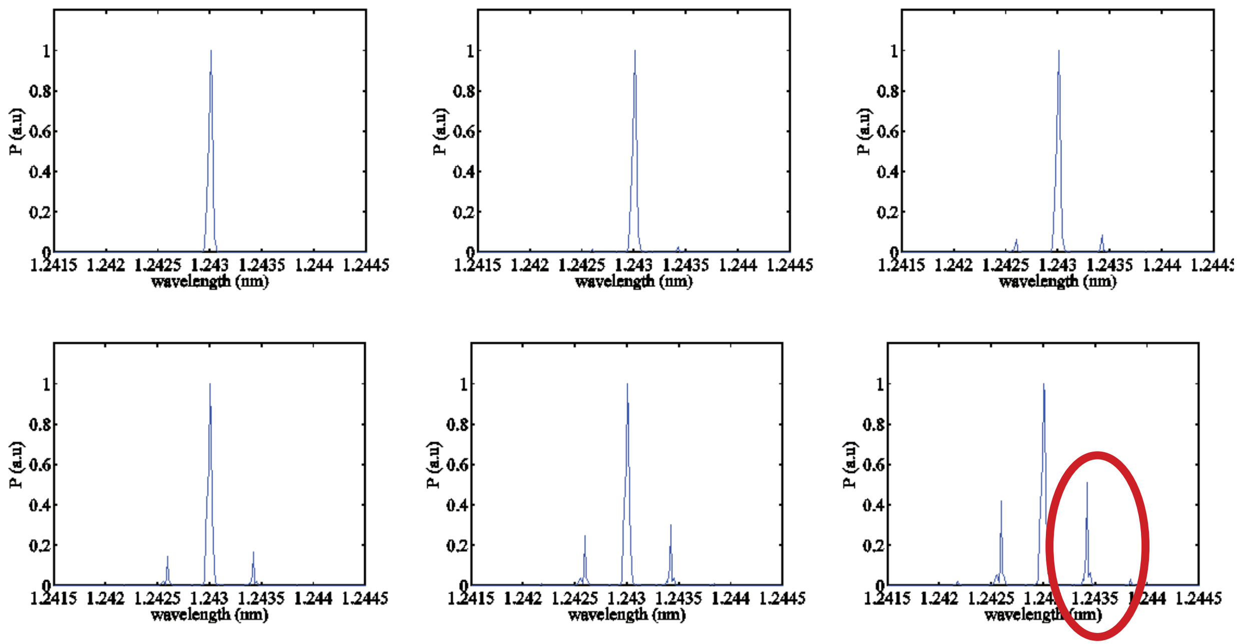
Prediction verification of sideband

$$\frac{P_s(\hat{z})}{P_1(\hat{z})} = \frac{\hat{A}^2}{9}\hat{z}^2 = \frac{4}{9}{A_0}^2{k_u}^2z^2$$

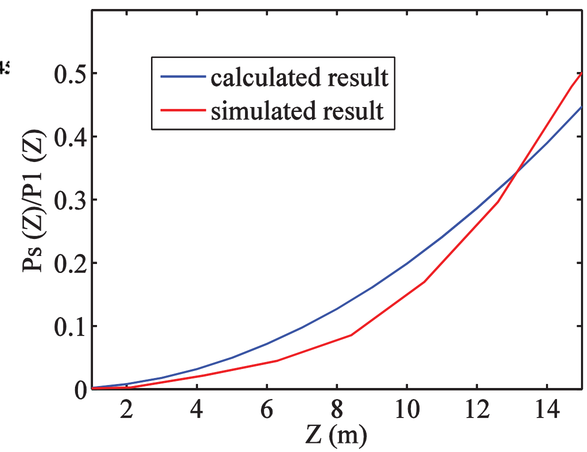
Modulation amplitude: 0.3 MeV
Modulation wavelength of 3.6 μm



Genesis simulation(single frequency modulation)



The simulation result is in accord with the theory prediction



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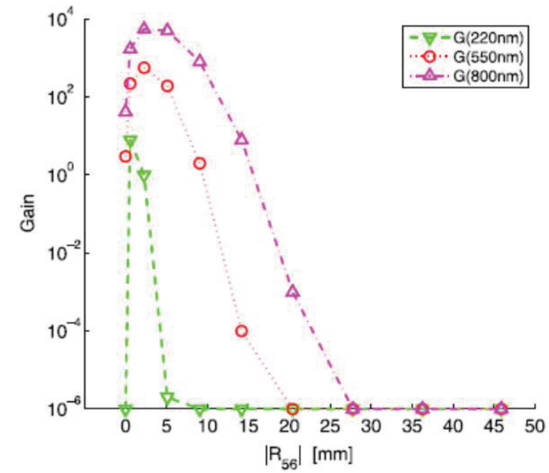
Kaiqing Zhang, et al, NIMA in Physics Research A 882 (2018) 22–29

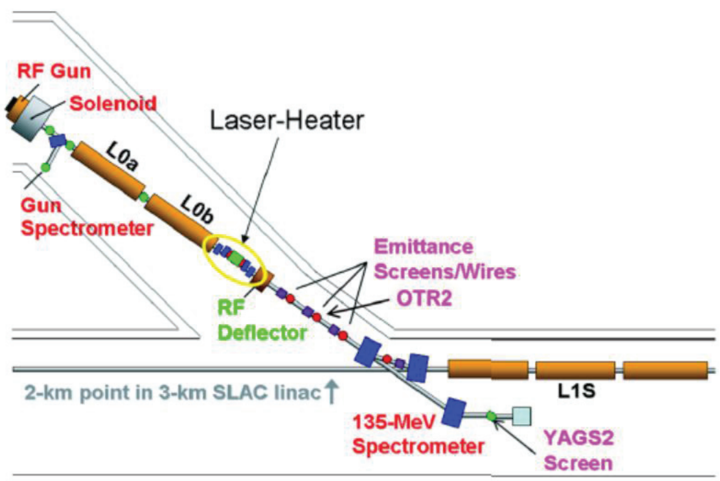
Michrobunching instability suppression

Microbunching Instability Suppression via Electron-Magnetic-Phase Mixing

S. Di Mitri[1,*] and S. Spampinati[1,2,3]
[1]*Elettra—Sincrotrone Trieste, 34149, Basovizza (TS), Italy*
[2]*University of Liverpool, Department of Physics, Liverpool, United Kingdom*
[3]*Cockroft Institute, Sci-Tech Daresbury, Warrington, United Kingdom*
(Received 5 December 2013; published 2 April 2014)

conclusion, we have demonstrated that magnetic-phase mixing is a viable alternative to the LH in controlling microbunching instability. Tunability of the wavelength at which the microbunching instability gain is suppressed is provided by the chicane's bending angle, thus ensuring a





Laser heater is the one efficient method to suppress the MBI, the sideband can be also suppressed to a certain level, but laser heater cann't be used to eliminate the MBI induced sideband

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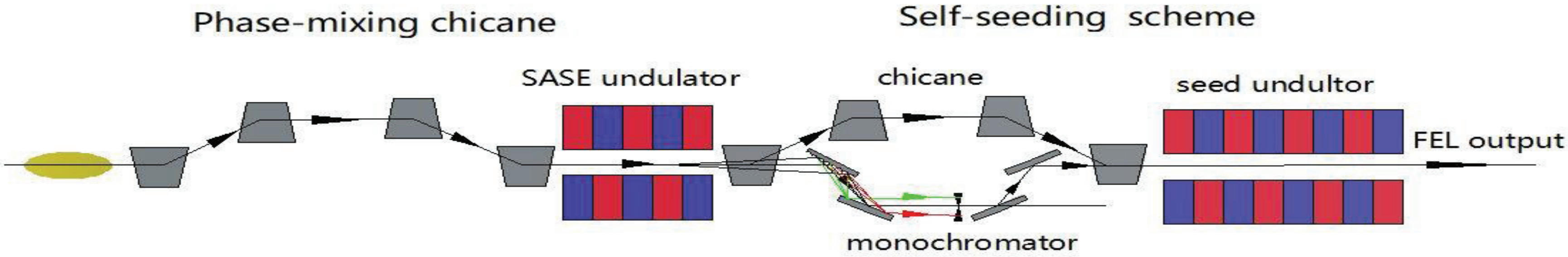
Eliminate sideband in SXSSF



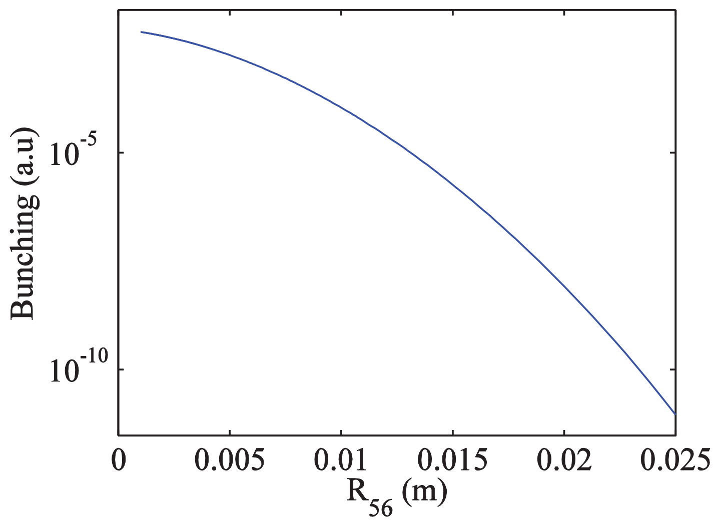
Efficient and easy to implement

Without chicane

$$b_{n,m} = \left| e^{-1/2[(Km+n)B_2]^2} J_m[-(Km+n)A_2B_2] \times J_n[-A_1(Km+n)B_2] \right|$$

With chicane

$$b_{n,m} = \left| e^{-1/2[nB_1+(Km+n)B_2]^2} J_m[-(Km+n)A_2B_2] \times J_n\{-A_1[nB_1+(Km+n)B_2]\} \right|$$



The sideband bunching decreases with the Intensity of the magnetic chicane

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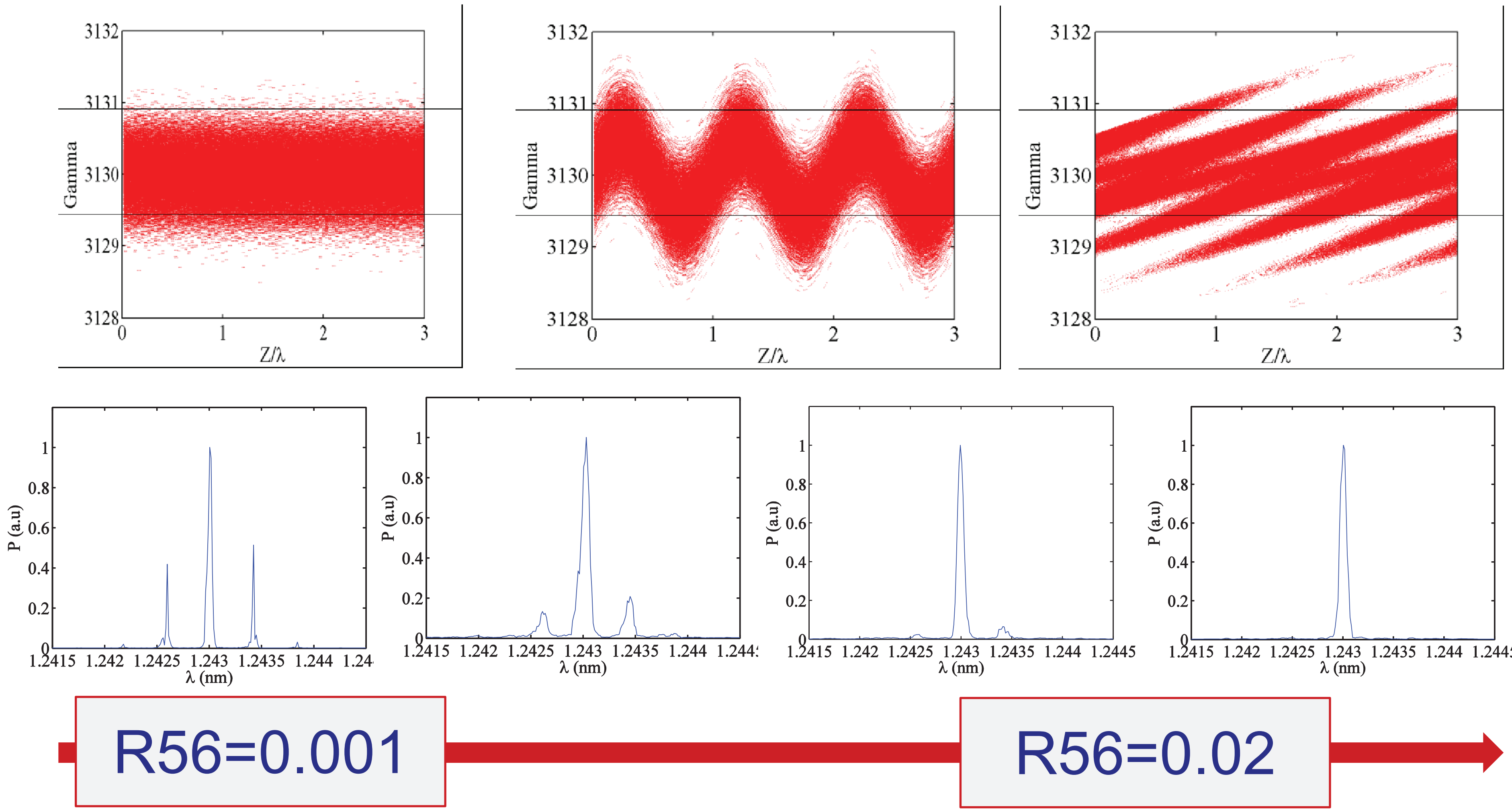
Eliminate sideband in SXSSF



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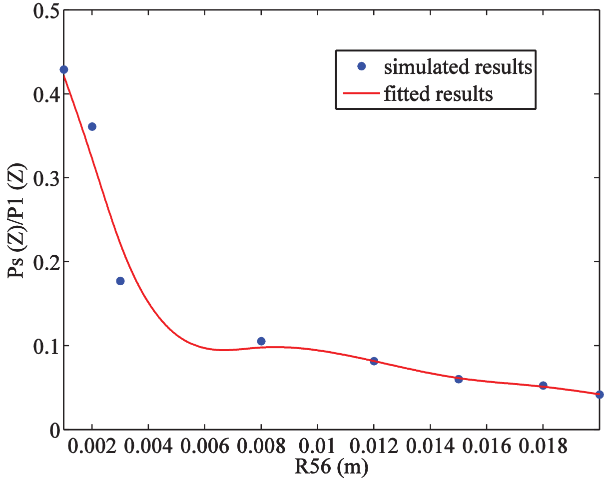
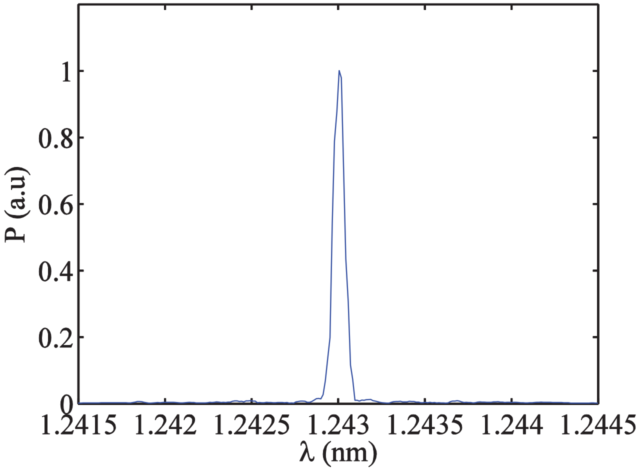
Eliminate sideband in SXSSF



Calculating the power ratio as a function of the strength of the magnetic chicane. The power ratio drops quickly with the increase of the intensity of the magnetic chicane

and the sideband is almost vanishing when the R_{56} reaches 15mm. The power of the coherent self-seeding signal is nearly unchanged for different strengths of the chicane



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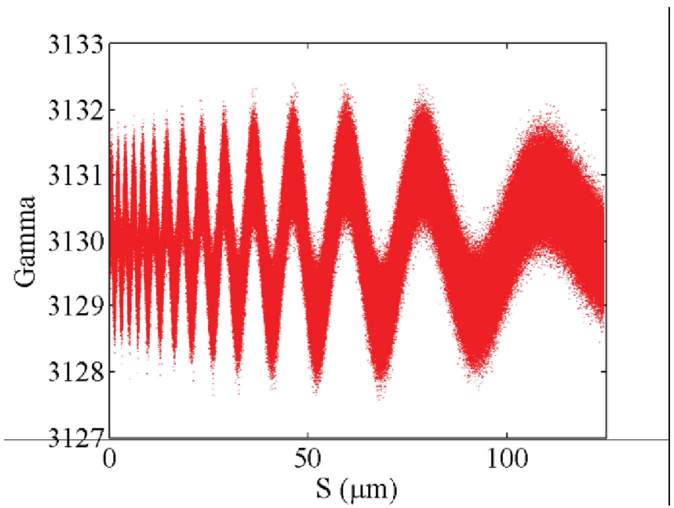
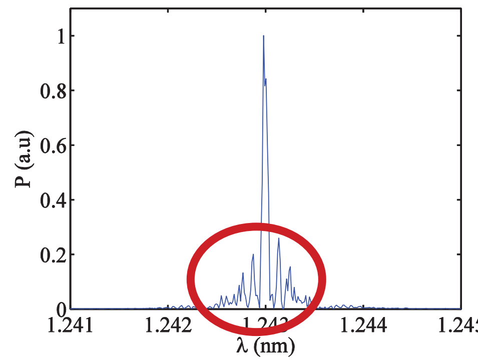
Eliminate sideband in SXSSF

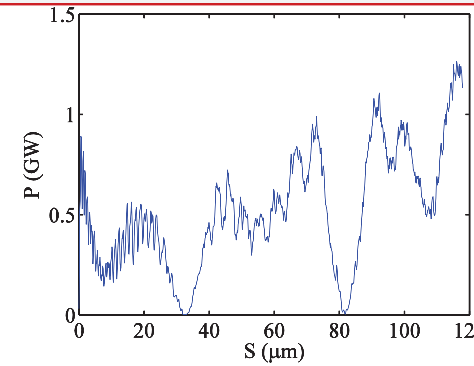
One more practical case utilizing a frequency chirped energy modulation electron beam

1.Pedestal-like sideband appears as predicted
2. The pedestal sideband is also eliminated by adding a magnetic chicane

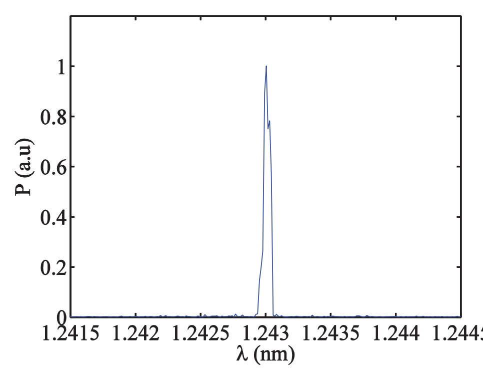


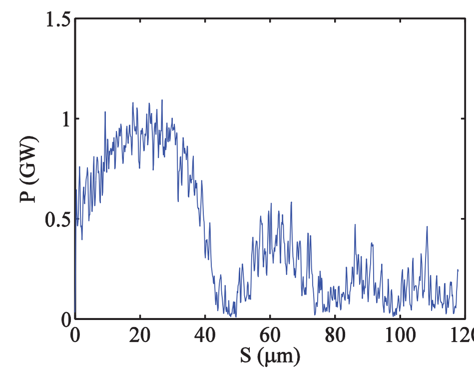
Without chicane：Pedestal-like sideband appears





With chicane：Pedestal-like sideband diappears





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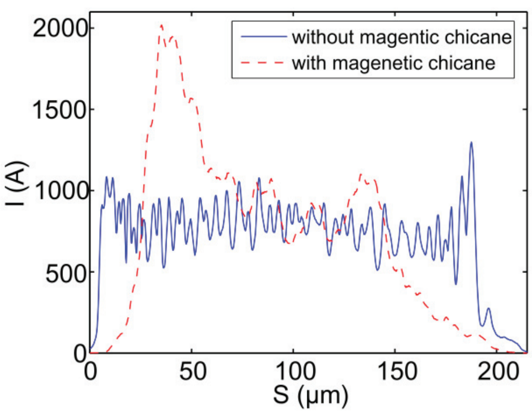
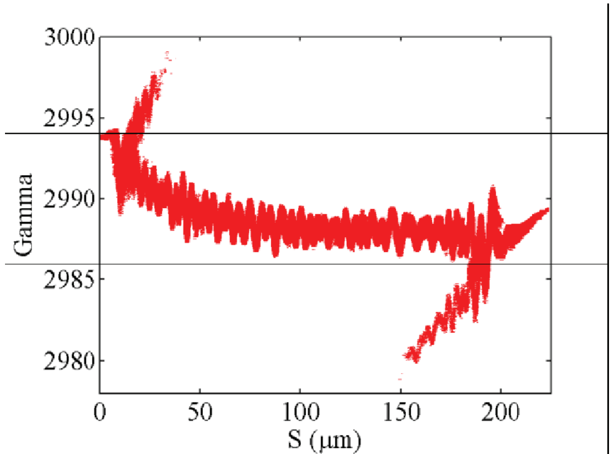
Eliminate sideband in SXSSF

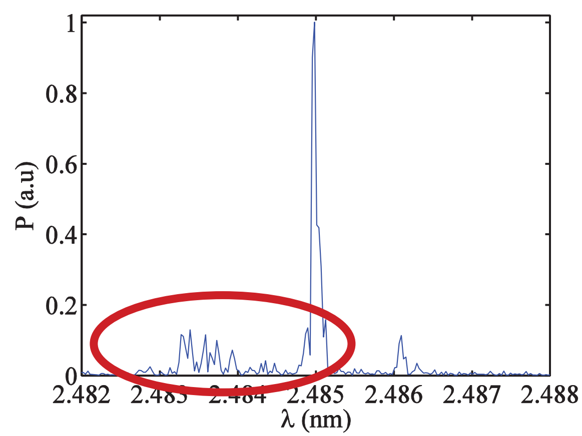
Start to end simulation

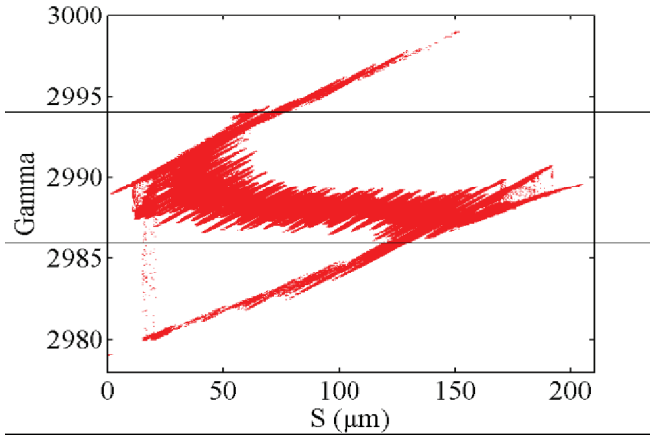
ELEGANT(SXFEL user facility LINAC—self-seeding simulation)



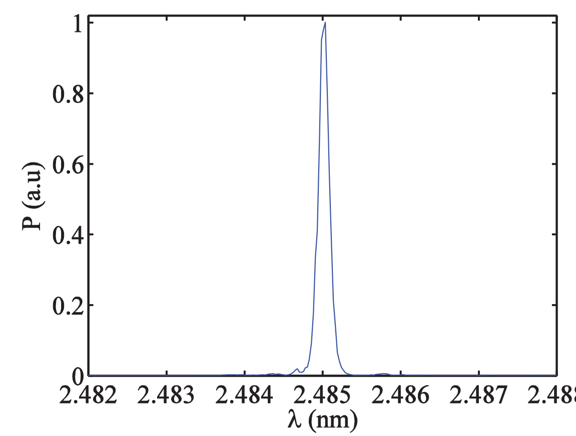


Without chicane





With chicane



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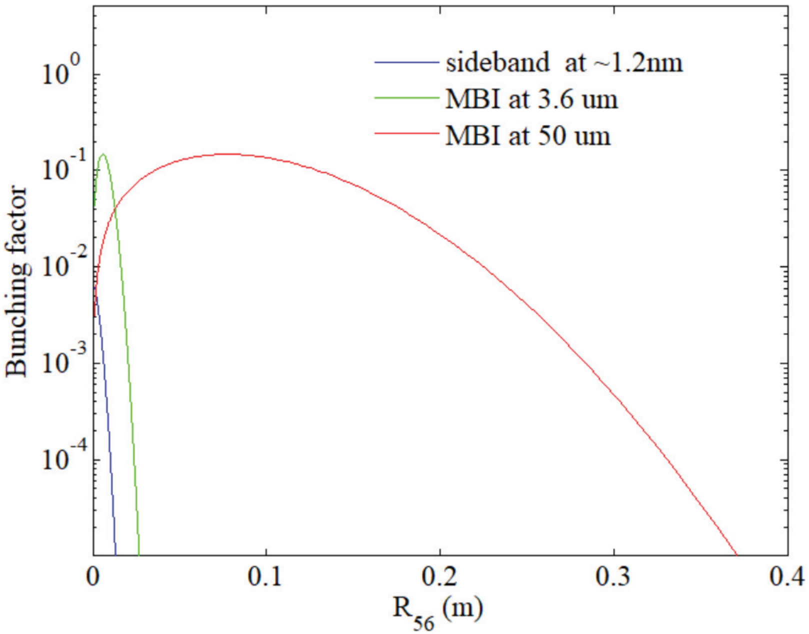
Eliminate sideband in SXSSF



the bunching factors between the MBI and the sideband as a function of the R56

1.The purpose of the proposed method is not to eliminate the MBI, but the MBI induced sidebands. The spectral sideband is caused by the frequency beat between the MBI at micrometer scale wavelength (2-10μm) and the coherent seed at x-ray wavelength.

2. You can find that the required R56 for smearing out the MBI at long wavelengths should be very large. Nevertheless, the required R56 for eliminating the MBI induced sideband is relative small

$$b_{n,m} = \left| e^{-1/2[nB_1+(Km+n)B_2]^2} J_m[-(Km+n)A_2B_2] \times J_n\{-A_1[nB_1+(Km+n)B_2]\} \right|$$

Conclusion

- [1]. Self-seeding process simulations with two cases are performed, and final simulation results are in accord with theoretical prediction

- [2]. An efficient method is proposed to suppress the pedestal-like sideband by adding a magnetic chicane before the self-seeding undulator

- [3]. The proposed method will make the self-seeding scheme to be much more credible in generation of high purified spectrum FEL radiation pulse.

- [4]. The proposed method can also be applied to a hard x-ray self-seeding FEL to suppress, or even eliminate the sideband

Thanks！

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