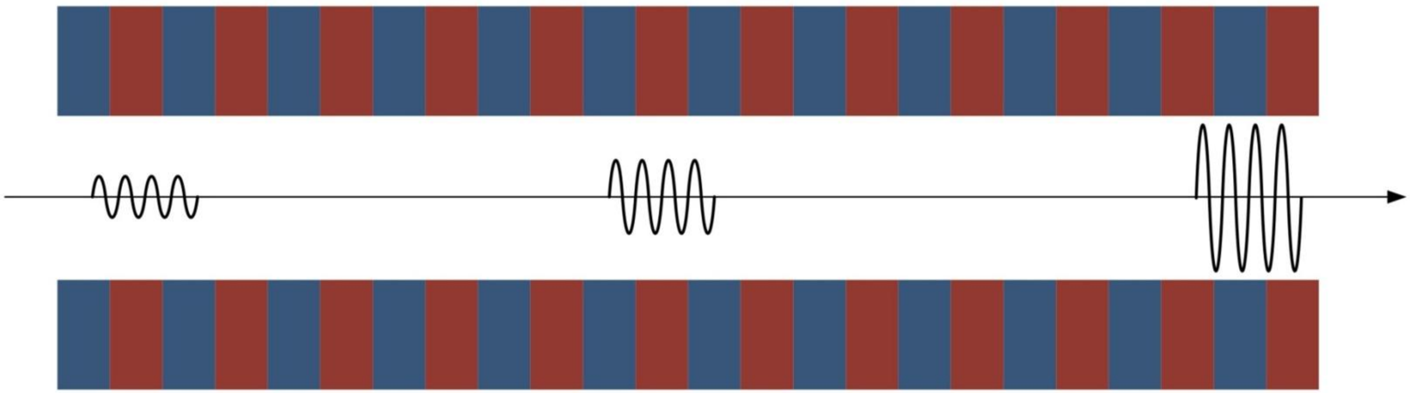
SELF SEEDING process in FELs

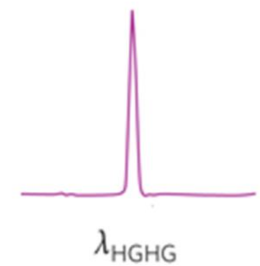
G. Campogiani, T. Rui, M. Sangroula, X. Xu

Outline

- Seeding: why do we need it?
- Types of seeding
- Self-seeding and its experimental setup
- Experimental results from LCLS
- Conclusion

Why seeding ?





FEL radiation starts from shot noise

Poor longitudinal coherence

Seeding increases longitudinal coherence by co-propagating a laser pulse with the e- beam.

Why Seeding (contd.)

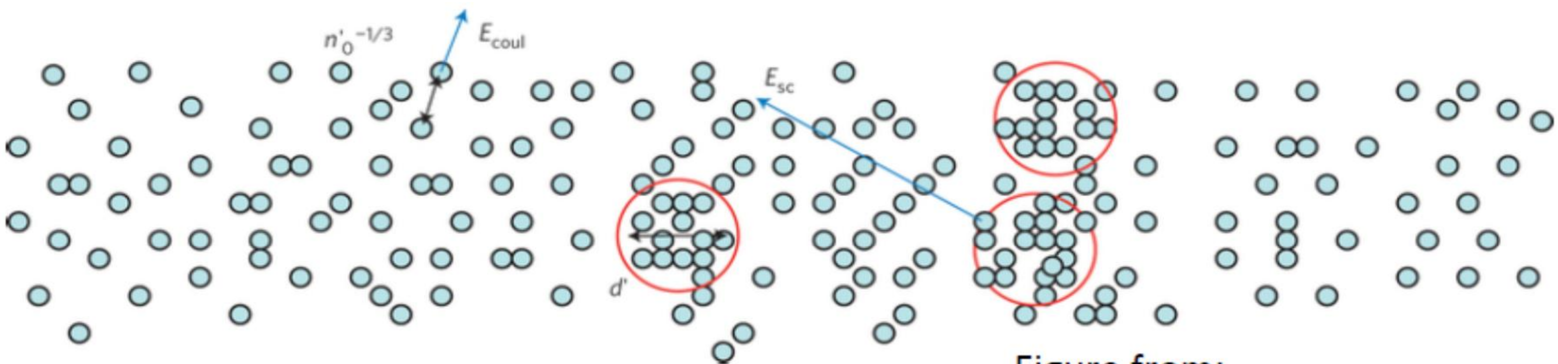


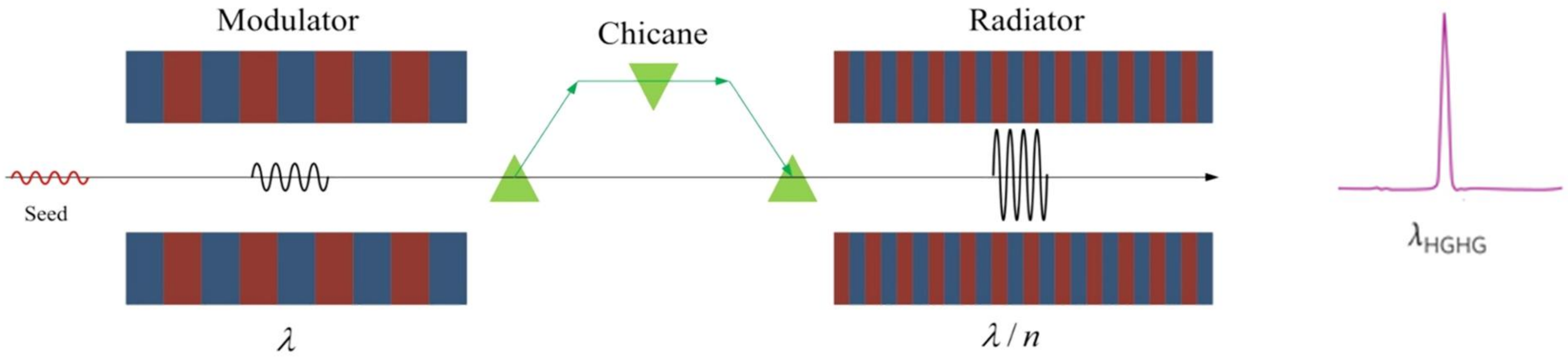
Figure from:
Avraham Gover et al.
Nature Physics **8**, 877–880 (2012)

- Longitudinal (temporal) coherence is inversely proportional to bandwidth.

- Seeding can allow a highly efficient *undulator field taper* to draw even more power from the electron bunch.

External seeding (HGHG)

High Gain Harmonic Generation

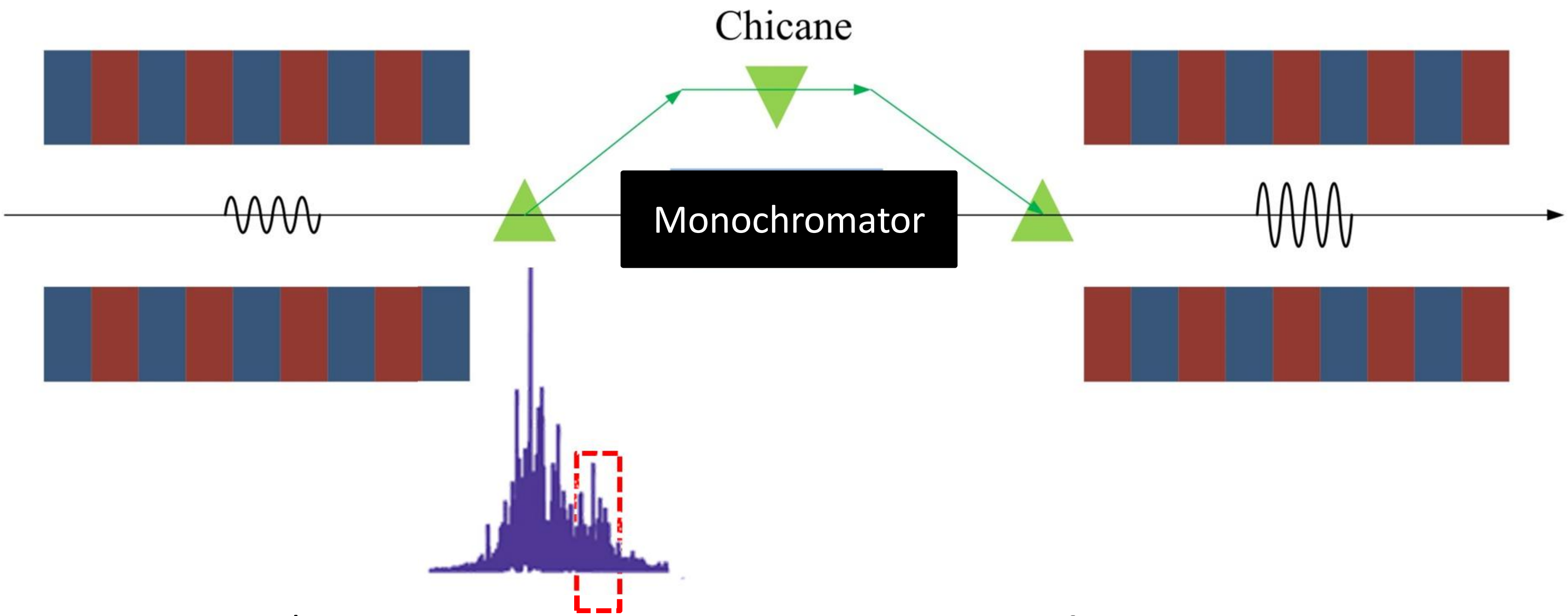


$$b_n \propto \exp\left(-\frac{D^2\delta^2}{2}n^2\right)$$

- We want to have a large bunching factor to get the coherence radiation and bunching factor decreases exponentially with harmonic number.
- To increase the bunching factor we need to have density modulation
- Chicane converts energy modulation to density (current) modulation.
- Radiator is tuned to one of the higher harmonics generally 3rd order harmonics.

Self-Seeding

- At first proposed by DESY in 1997



1st stage operates as conventional SASE FEL

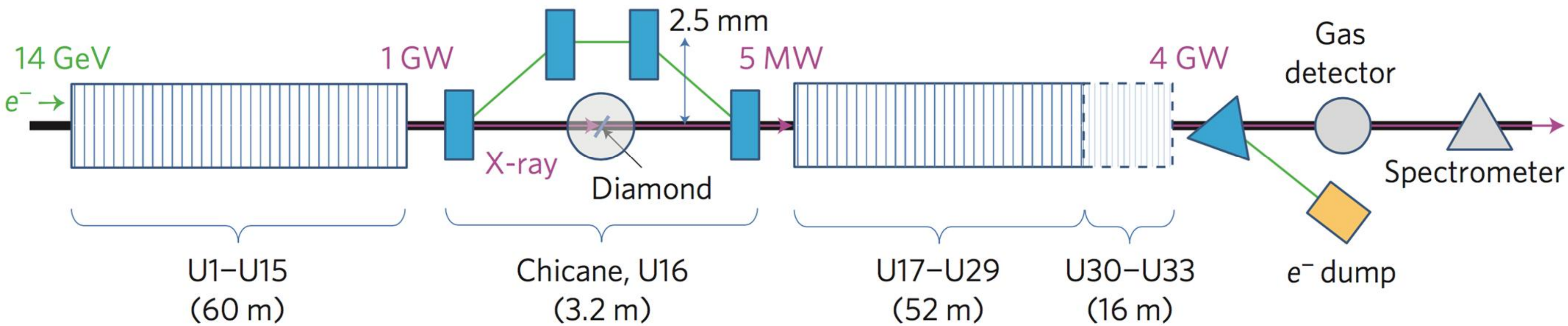
Radiation is filtered by monochromator

Filtered X-rays act as a seed in 2nd stage

External vs Self-Seeding

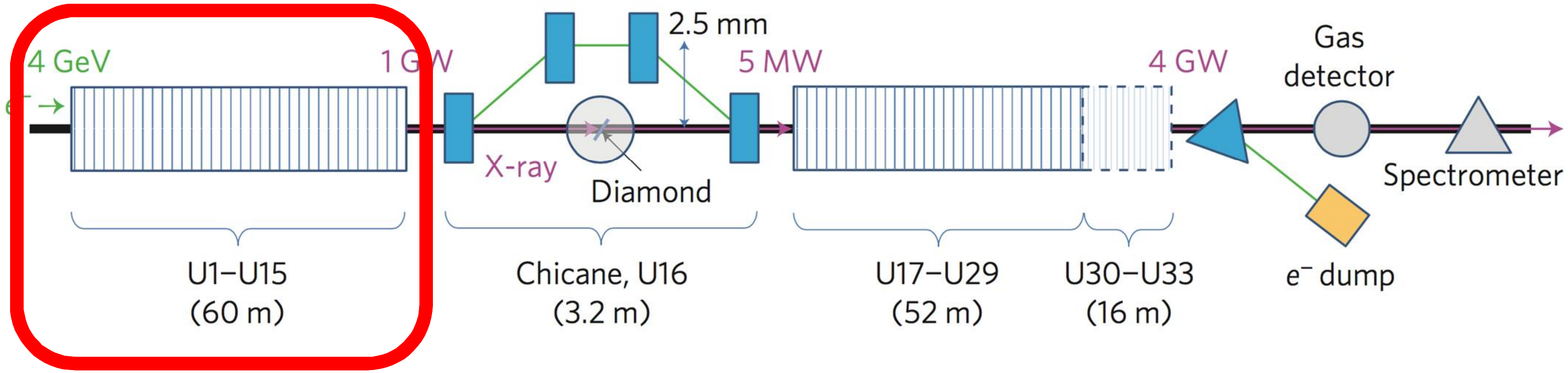
Method	Direct Seeding (HHG)	HGHG Cas. or EEHG	Self-Seeding
Wave Length Limit	>20 nm	> 1nm	> 0.1 Å
Synchronization	Good	Good	None
Brilliance	Similar to SASE (penalty from seed BW)	Slightly better (penalty from lower current)	Much better than SASE
Pulse Length	~10 fs	10 – 100 fs	As electron bunch
Signal-to-Background	Poor	Moderate - Good	Excellent
Complexity	Moderate (excluding source)	High	Moderate
Electron Beam Requirement	Arrival time and energy stability	Arrival time and energy stability, lower energy spread	Energy stability
Undulator Length	Slightly less than SASE FEL	Comparable and longer than SASE FEL	50% longer than SASE FEL

Experimental setup @LCLS



Experimental setup @LCLS

Power exiting the 1st stage



Power gained from the 1st stage

- The SASE process in the 1st stage should supply enough pulse energy and do not spoil the beam quality (mainly in energy spread)

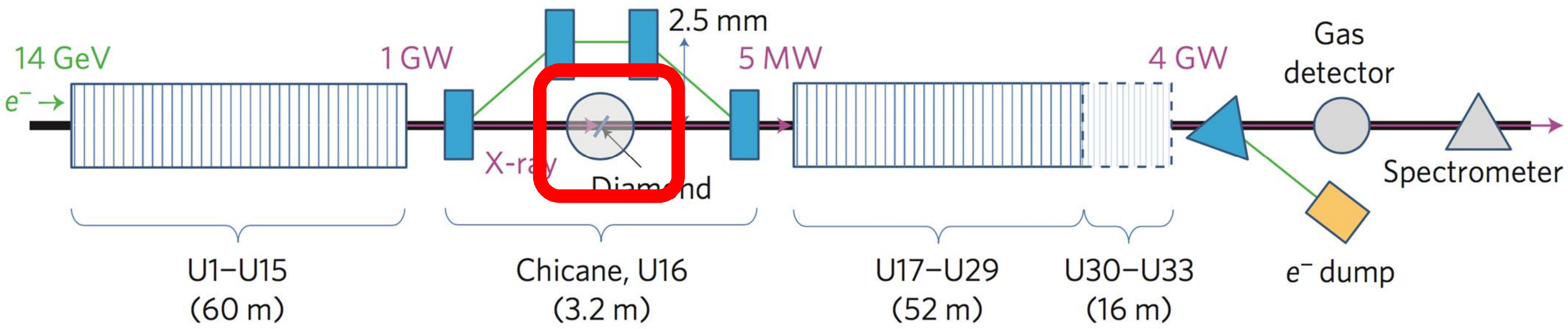
$$P_{SASE} = \alpha P_n \exp\left(\frac{z}{L_g}\right) \times G >> P_n$$

$$P_n = 6\sqrt{\pi}\rho^2 \frac{P_b}{N\sqrt{log(N/\rho)}}$$

✓ LCLS Hard X-ray: ~ 1 GW@~60 m

Experimental setup @LCLS

Monochromator



The Monochromator

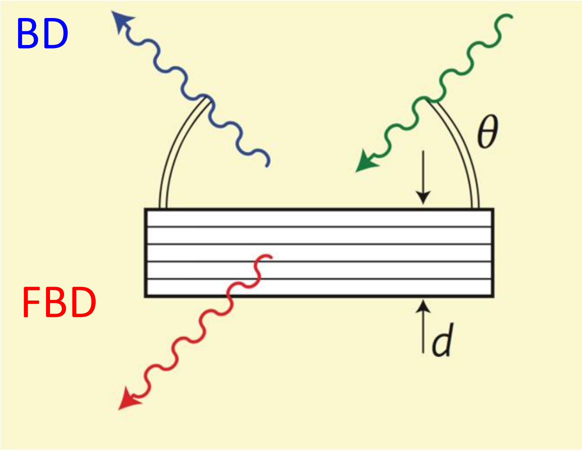
- Filter only a very narrow bandwidth

✓ Silicon or Diamond crystal (5~10 ps)

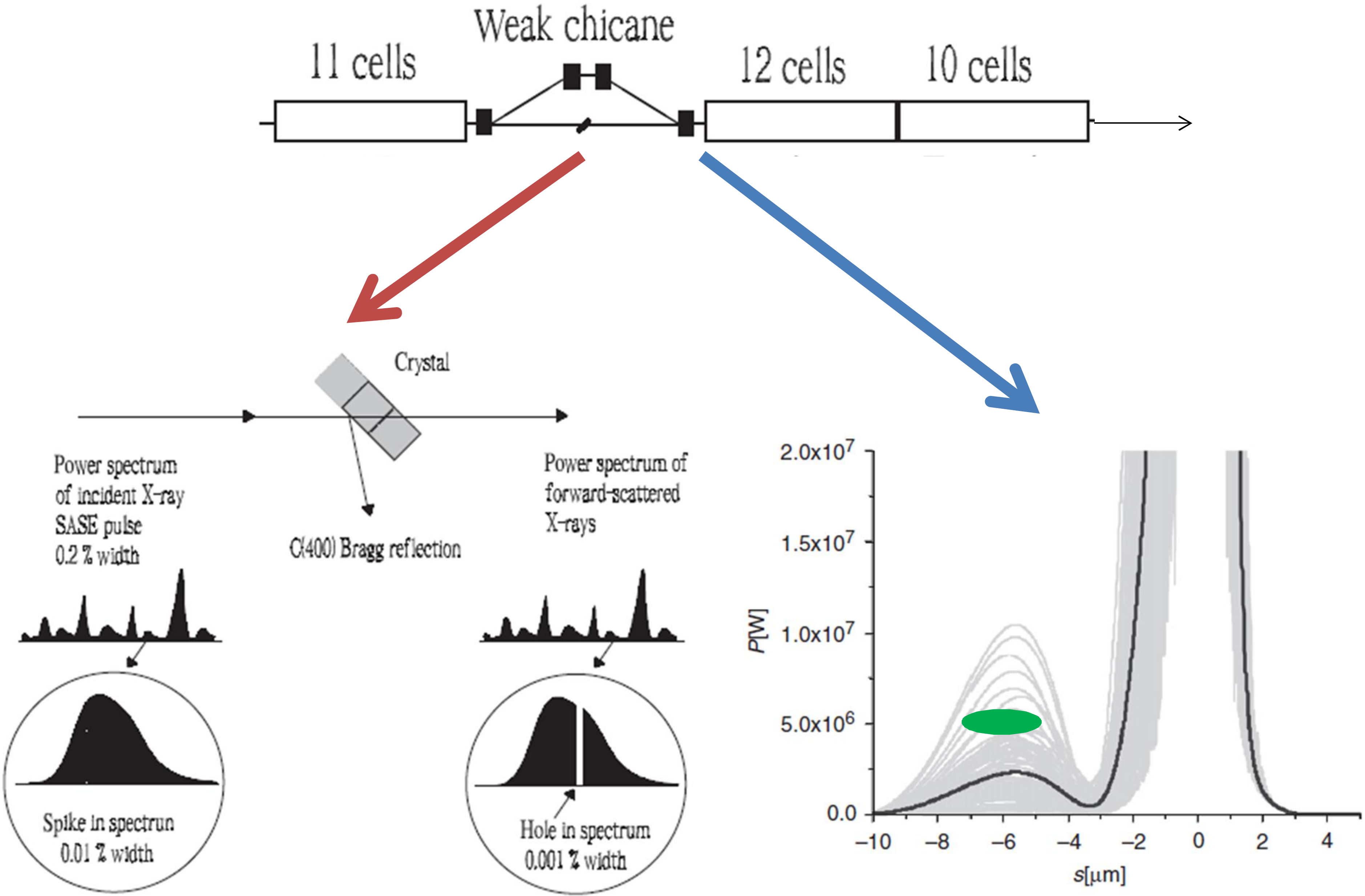
✓ A single diamond crystal in a forward Bragg diffraction (FBD) geometry

Delay: ~10s fs

Bandwidth: ~0.1 eV

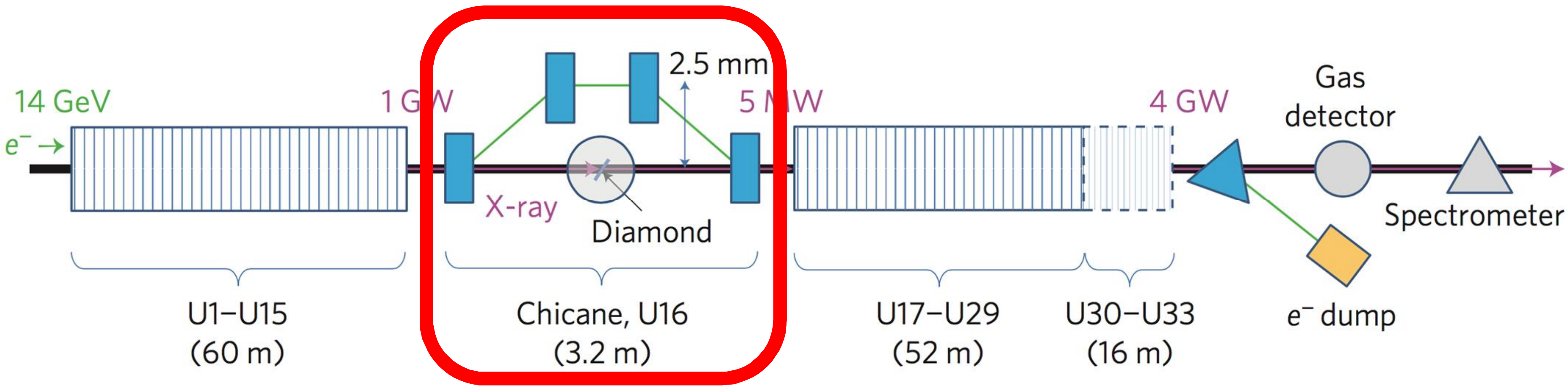


Time windowing



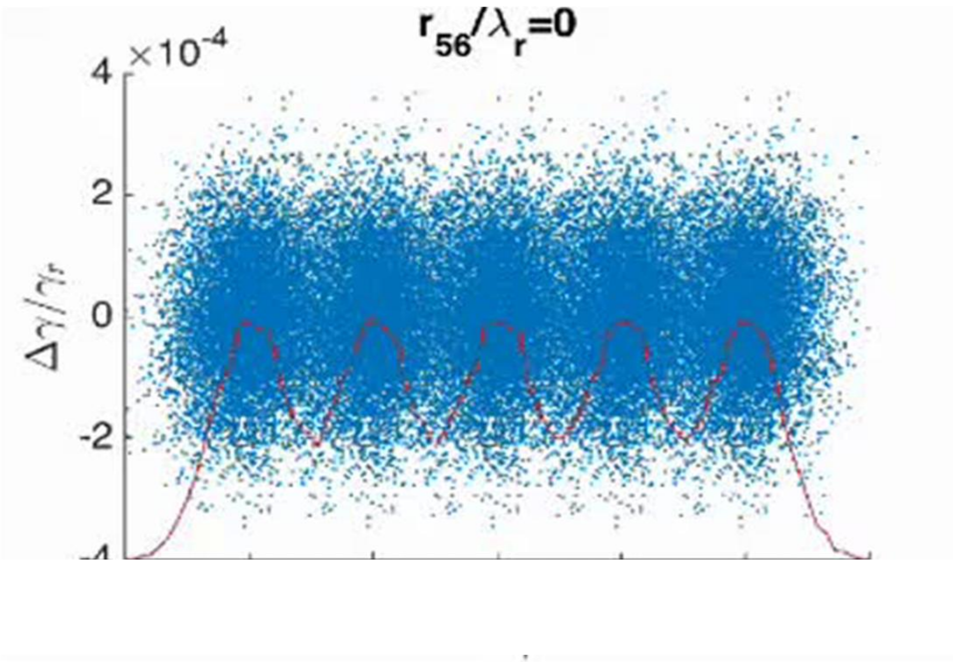
Experimental setup @LCLS

Chicane



The Role of the Chicane

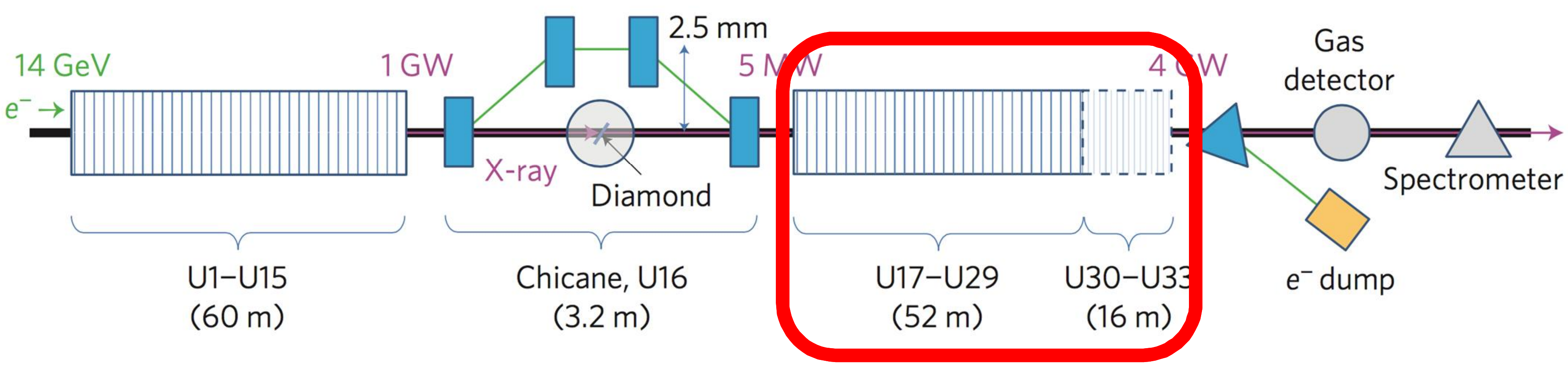
- Let the electrons to be delayed and overlapped with radiation at the entrance of second undulator
- Wash out the bunching on the radiation wavelength



$$r_{56}\frac{\Delta\gamma}{\gamma} \sim \lambda_r$$

Experimental setup @LCLS

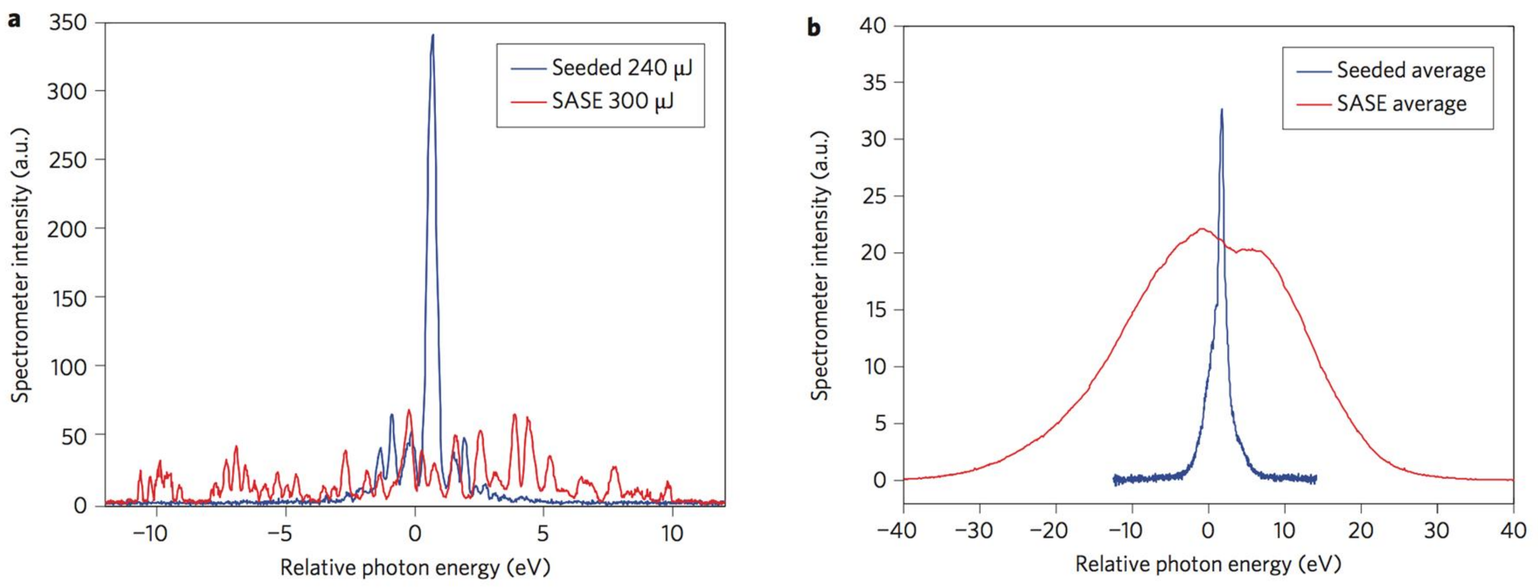
Seeded-FEL in the 2nd stage



Seeded-FEL in the Second Stage

- Experimental Results

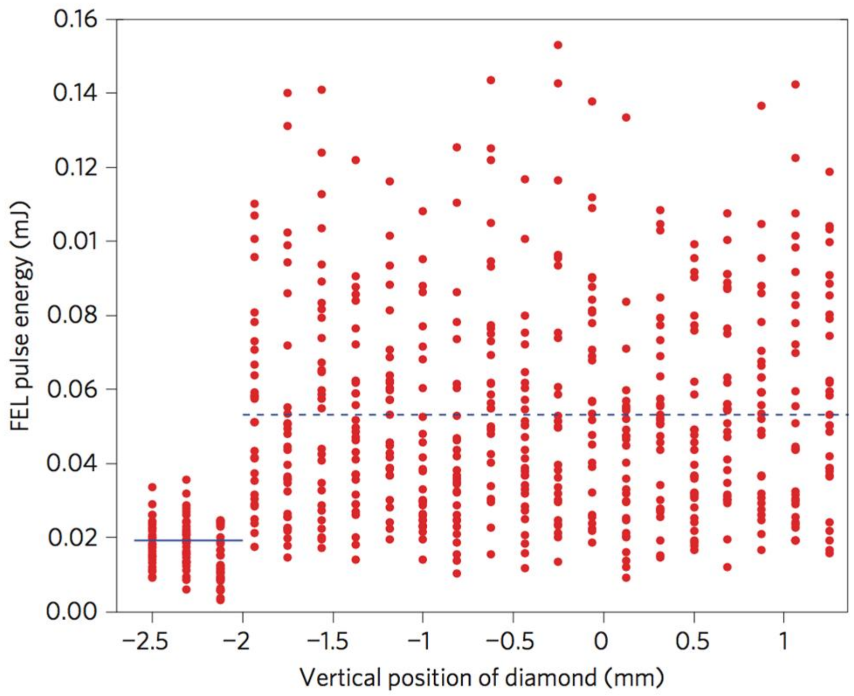
✓ Bandwidth: reduced from ~20 eV to 0.4~0.5 eV



Output power

- Experimental Results

✓ Power stability: ~50% r.m.s. fluctuations



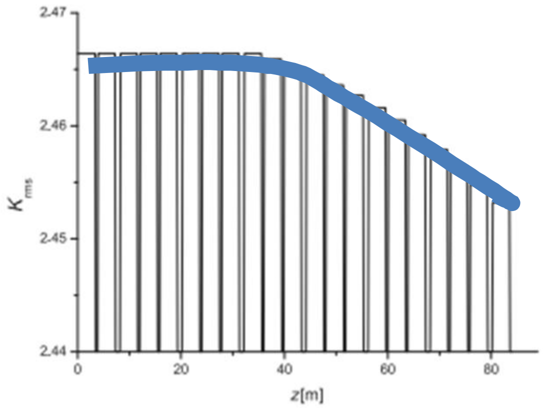
Reasons:

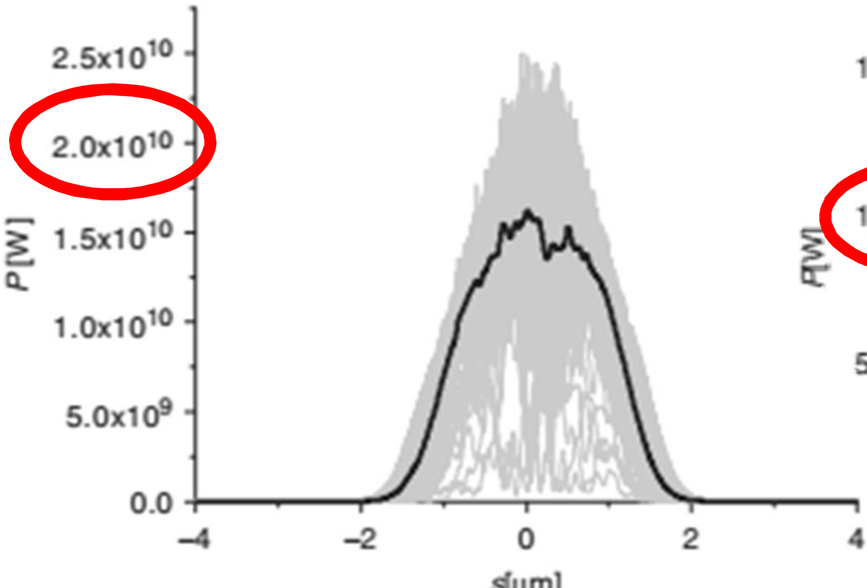
1. shot-to-shot seed power variations.
2. shot-to-shot electron energy variations.
3. FEL in the second undulator does not saturate.

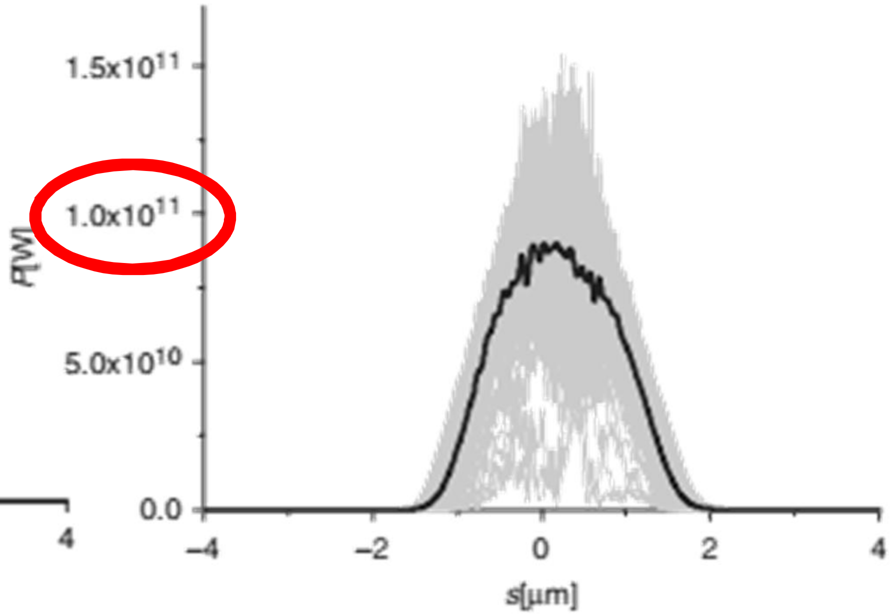
Tapering

- To enhance the output power
- K modulated to follow the energy loss evolution

$$\lambda \approx \frac{\lambda_u}{2\gamma^2}\left(1+\frac{K^2}{2}\right)$$







Take away

- Self-Seeding is the only scheme that improves FEL longitudinal coherence at hard x-rays by reducing the bandwidth of the photon pulse
- There are several knobs to play with in terms of monochromator, undulator and chicane parameters
- More schemes could be developed in the future

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THANK YOU