Distributed Seeding for Narrow-band X-ray Free-Electron Lasers

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37th International FEL Conference

23-28 August, 2015

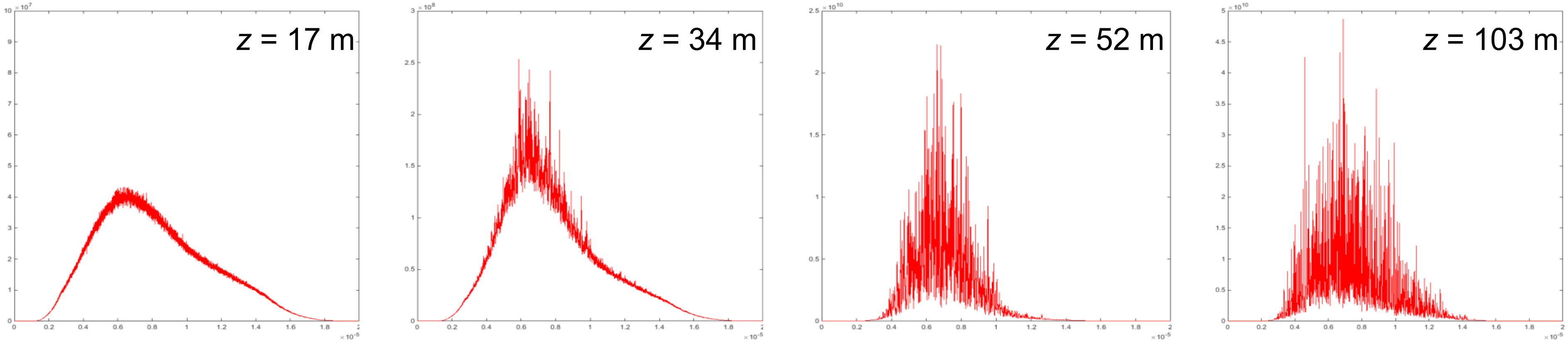
Daejeon, Korea

Outline

- SASE Self-Seeding
- Distributed Seeding (DS)
- MaRIE X-ray FEL
- Time-dependent Genesis Simulations
- Summary

SASE spikes form during exponential growth

Power versus s plots



Radiation pulse resembles electron current profile. Radiation spectra peak at wavelength longer than λ_0

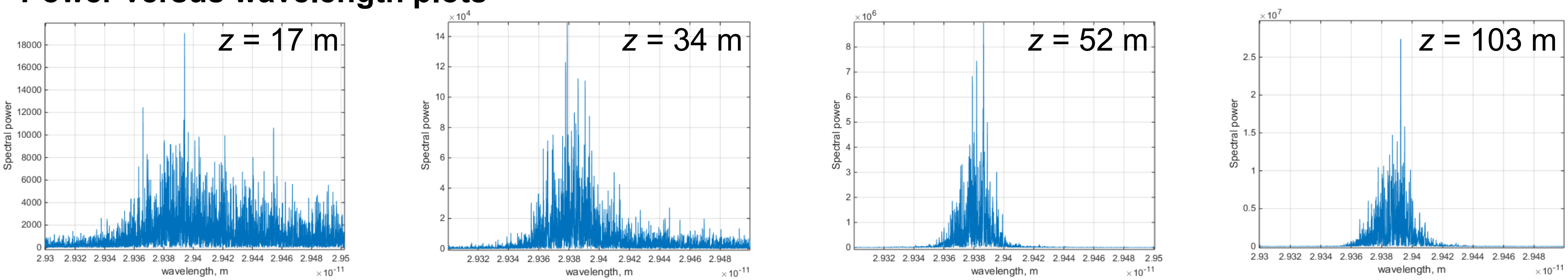
SASE spikes appear in exponential growth regime. Spectral peak shifts toward resonance wavelength λ_0

At saturation, SASE spikes have a coherence length of

$$l_c = \frac{\lambda}{2\sqrt{\pi}\rho}$$

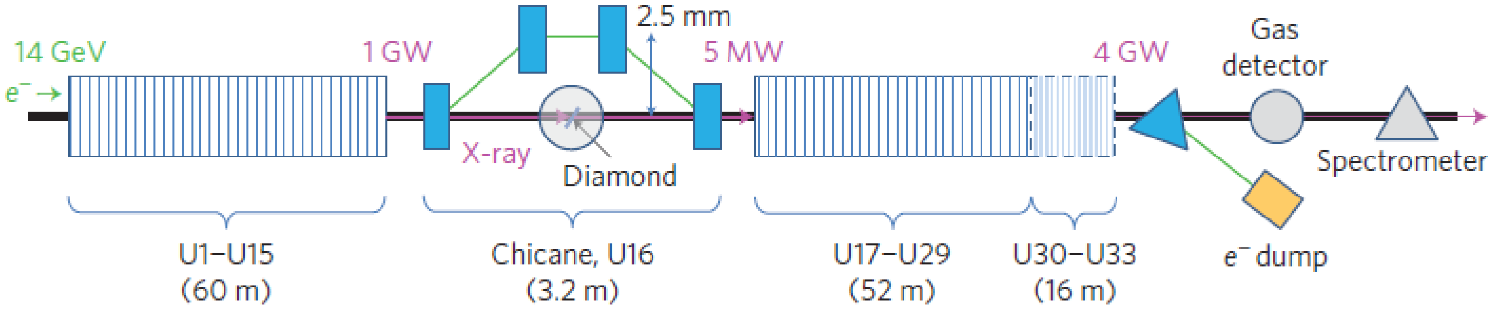
More SASE spikes are added beyond saturation. Spectra broaden and shift to slightly longer wavelength.

Power versus wavelength plots

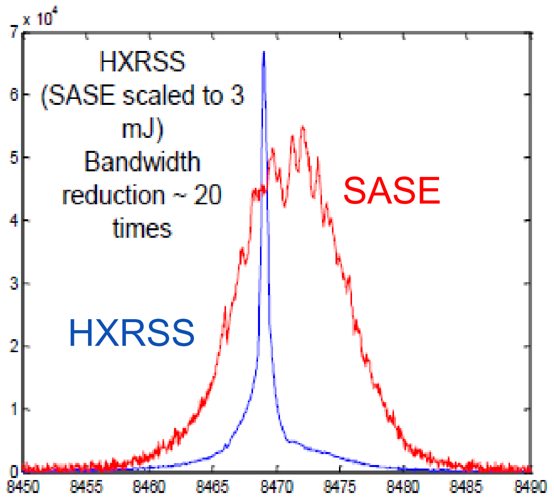


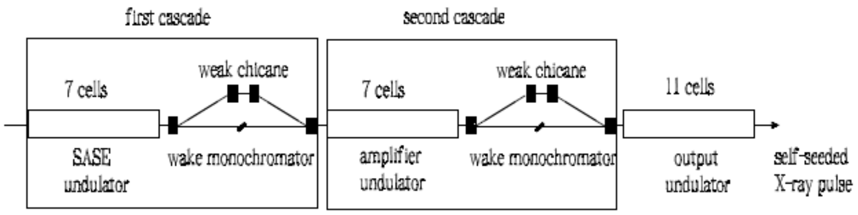
SASE Self-Seeding

Hard X-ray Self-Seeding (HXRSS) has been demonstrated at LCLS and SACLA



Ref: J. Amann *et al*., *Nature Photonics* **6**, 693-698 (2012).



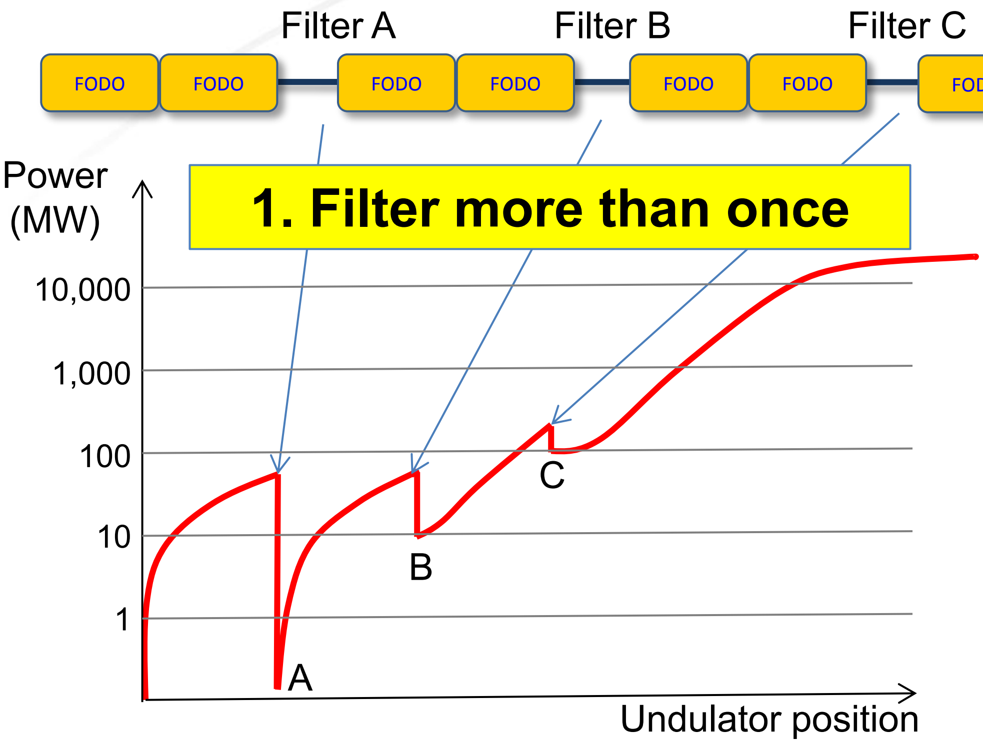


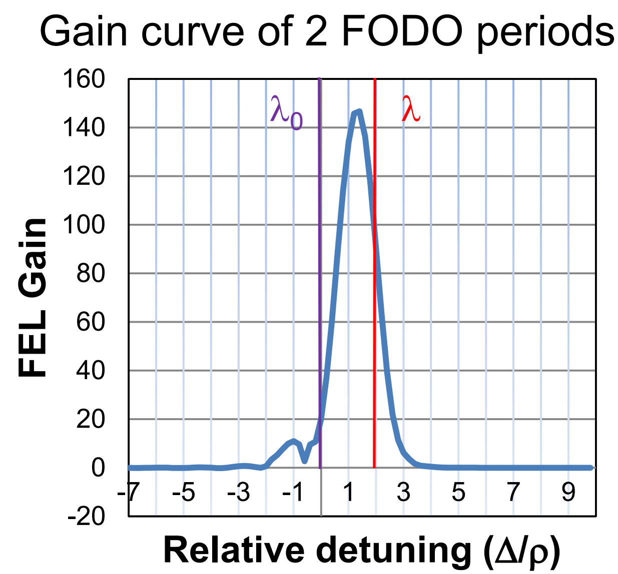
Ref: L. Geloni *et al*., DESY **10-080**, (2010).

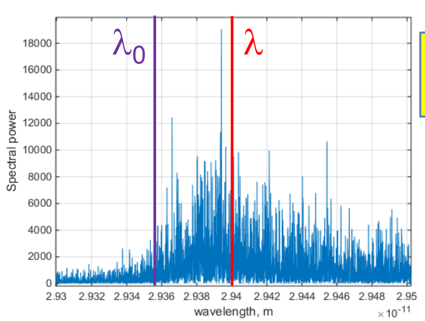
SASE background contributes to about one-half of HXRSS radiation energy. Geloni *et al*. proposed cascade self-seeding to improve HXRSS contrast.

Distributed Seeding (DS)

1. Filter more than once





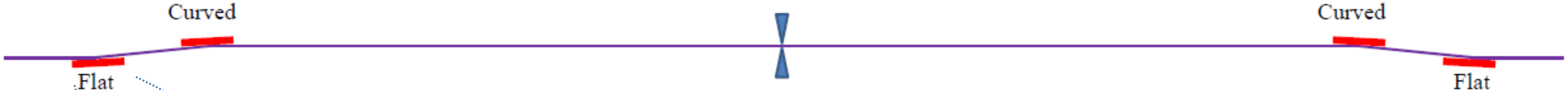


2. Filter before SASE spikes appear

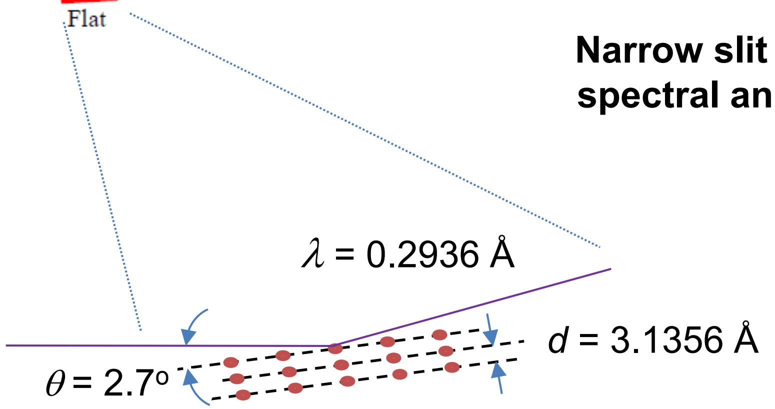
3. Filter at a wavelength longer than λ_0

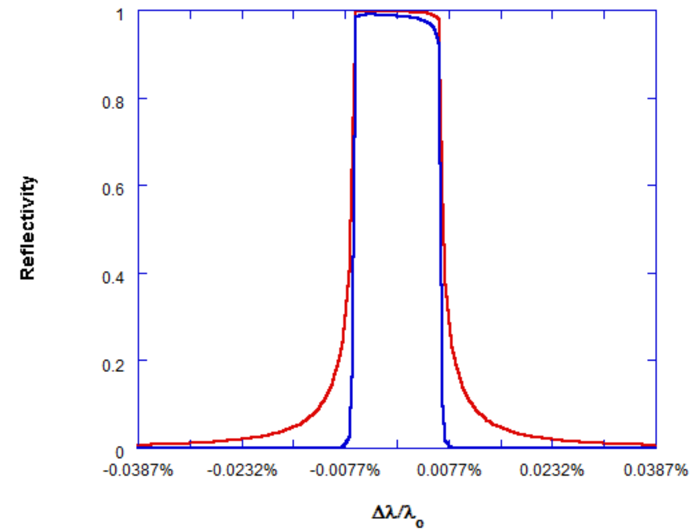
Four-bounce Bragg crystal monochromator

Each Si(111) crystal deflects X-ray beam by ±5.4°; total deflection is zero.

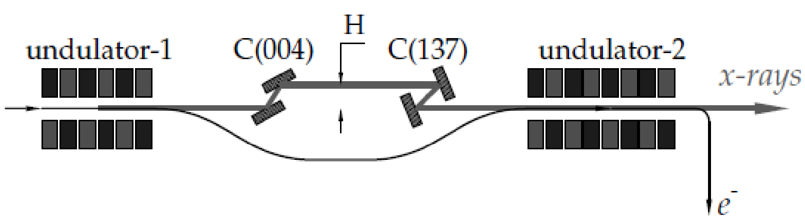


Narrow slit serves as both spectral and spatial filters





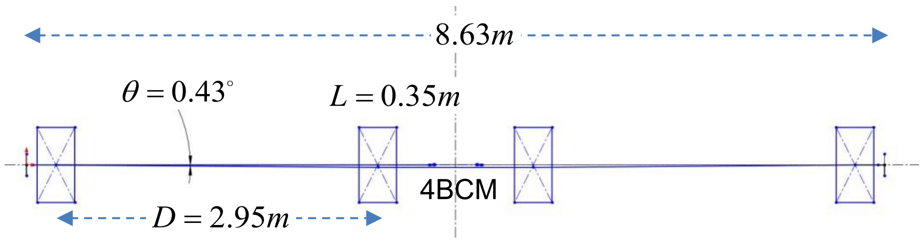
Si(111) Spectral Response



Four-bounce Bragg crystal monochromators (4BCM) have been proposed for SASE self-seeding

Ref: E.L. Saldin *et al*., Nucl. Instr. Met. Phys. Res. **475** (2001) 357-362.

Small-angle chicanes introduce 1-ps delay in electron path, matching the delay of 4BCM

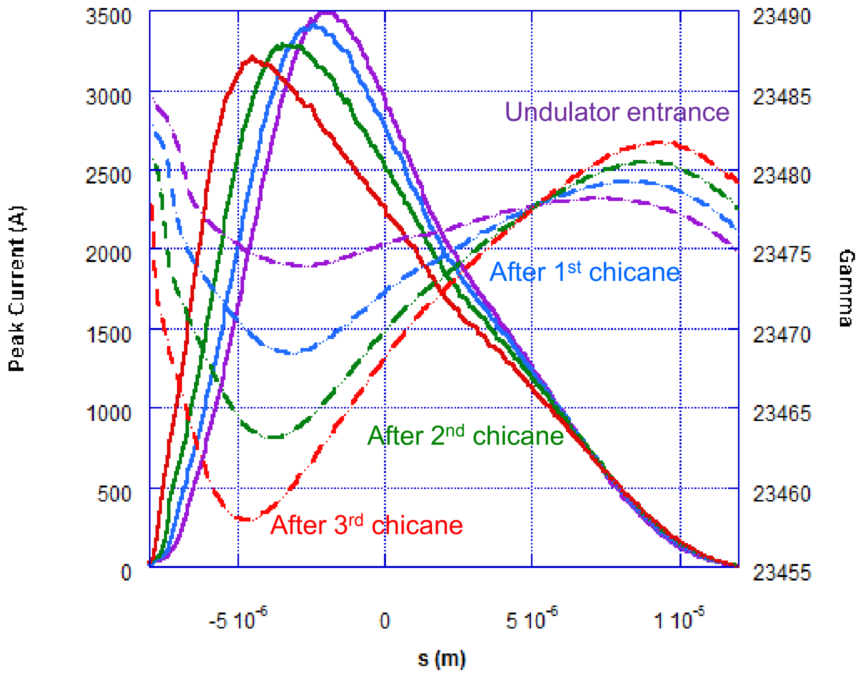


Delay in electron beam path

$$\Delta S_e = R_{56} = -\theta^2\left(\frac{4}{3}L + 2D\right)$$

Chicane R_{56} is sufficiently large to erase SASE-induced microbunching.

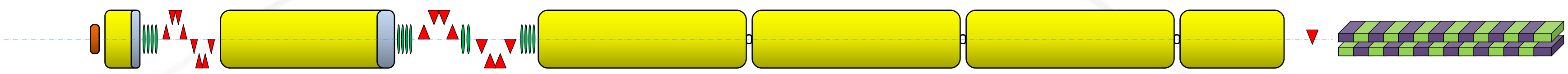
$$\lambda << |R_{56}|\frac{\sigma_\gamma}{\gamma}$$



The main effects are CSR-induced reduction in the slice beam energy and peak current.

Spoiling SASE microbunching = fresh bunch re-injection

MaRIE X-ray FEL
(Matter-Radiation Interactions at Extremes)

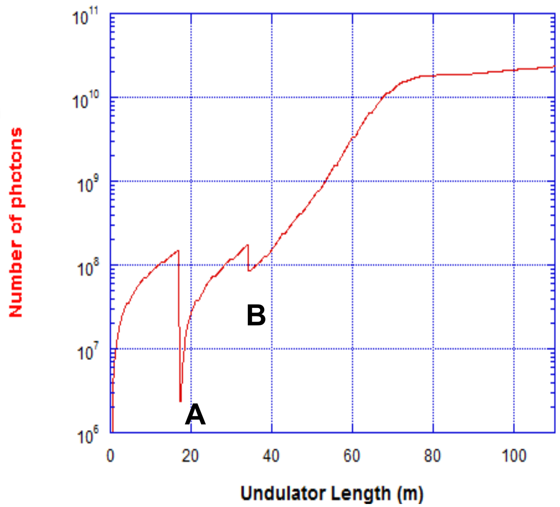


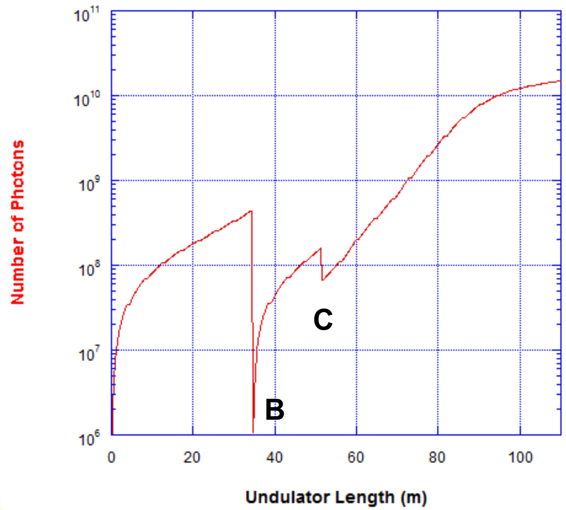
Parameter	Symbol	Value	Unit
Electron beam energy	E_b	12	GeV
Peak current	I_{pk}	3	kA
Bunch charge	Q	100	pC
Slice normalized emittance	ε_n	0.2	μm
Slice energy spread	σ_γ/γ	0.015%	
Undulator period	λ_u	18.6	mm
Peak undulator parameter	K	1.22	
Wavelength	λ	0.2936	Å
1-D FEL gain parameter	ρ	0.05%	
3-D gain length	L_{G3D}	2.5	m

Details presented in Poster MOP045

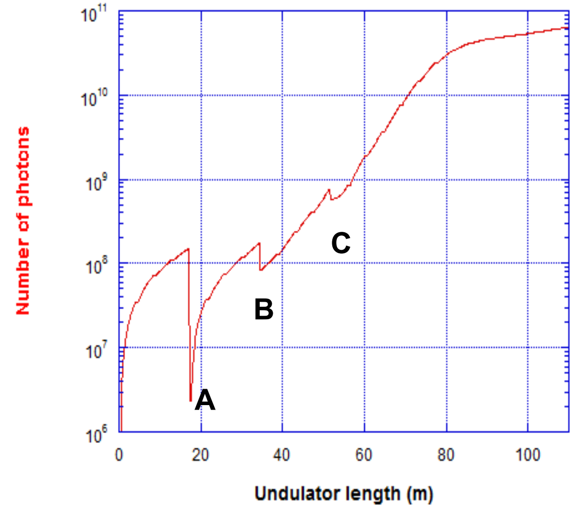
Plots of number of photons versus z for DS

Two-stage DS



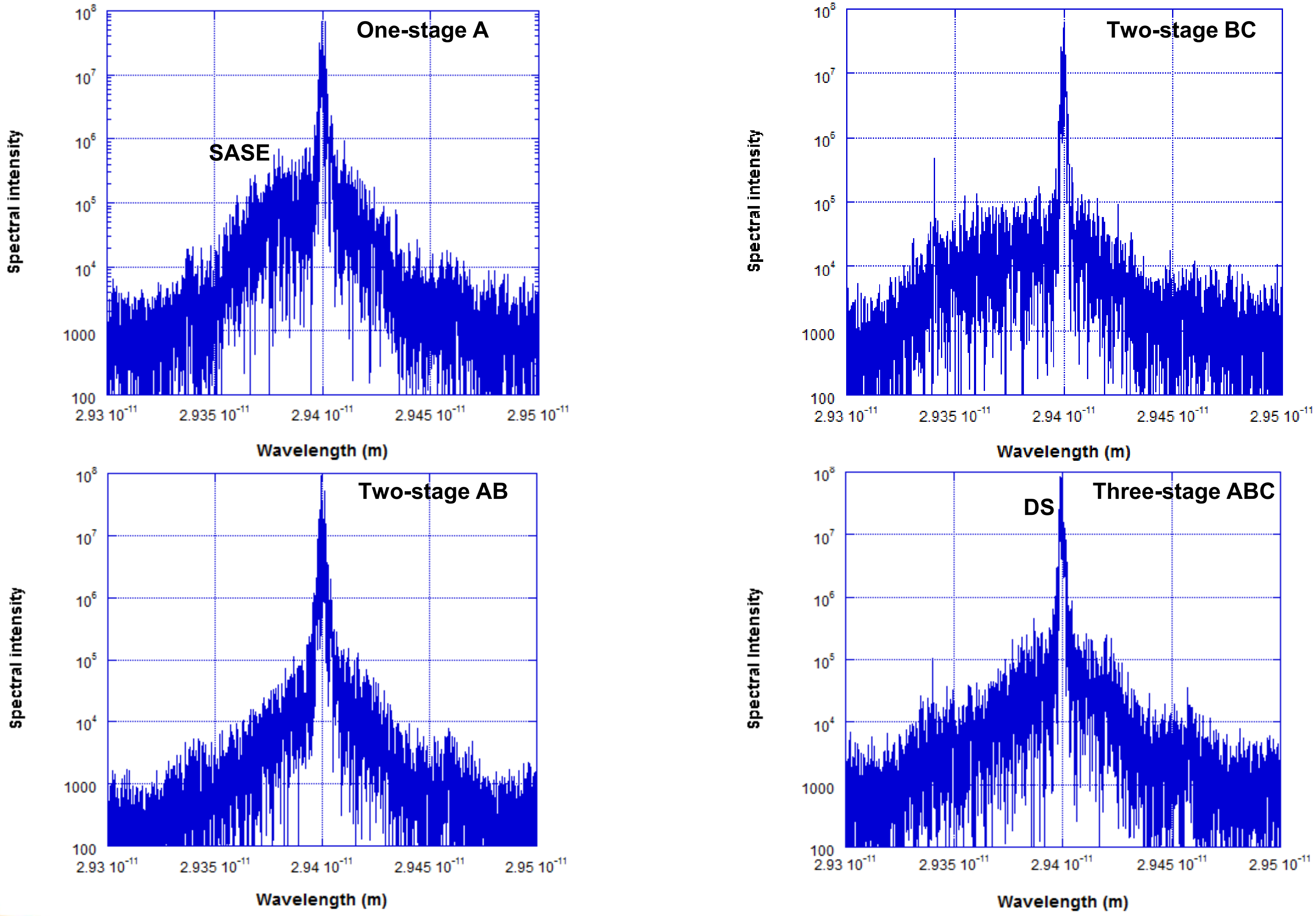


Three-stage DS



Number of photons increases exponentially with z immediately after the 2nd and 3rd filters.

DS yields higher contrast over SASE than SS
Three-stage DS achieves 0.008% bandwidth



Summary

- **DS differs from SASE Self-Seeding in three aspects: Filter more than once, filter before SASE spikes appear, and filter at a longer wavelength.**
- **Filtering at a wavelength longer than the resonance wavelength improves the contrast between the narrow-line DS signal and broadband SASE.**
- **Both two-stage and three-stage DS produce <0.01% relative bandwidth.**
- **Time-dependent Genesis simulations show the three-stage DS can deliver >2 x 10^{10} photons/bunch at 42 keV for the MaRIE XFEL.**

But will it work in the real world?

DS has been running for years!

THANK YOU