Harmonic Self-Seeding for the MaRIE X-ray FEL

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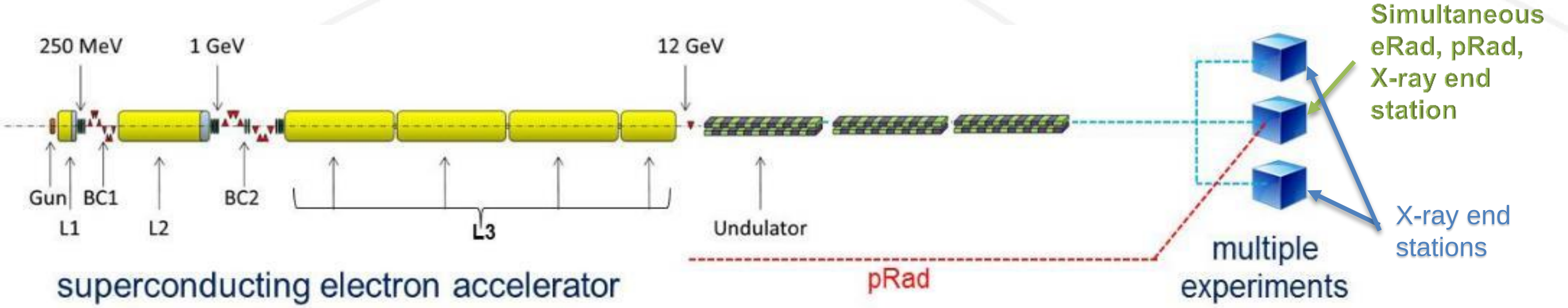
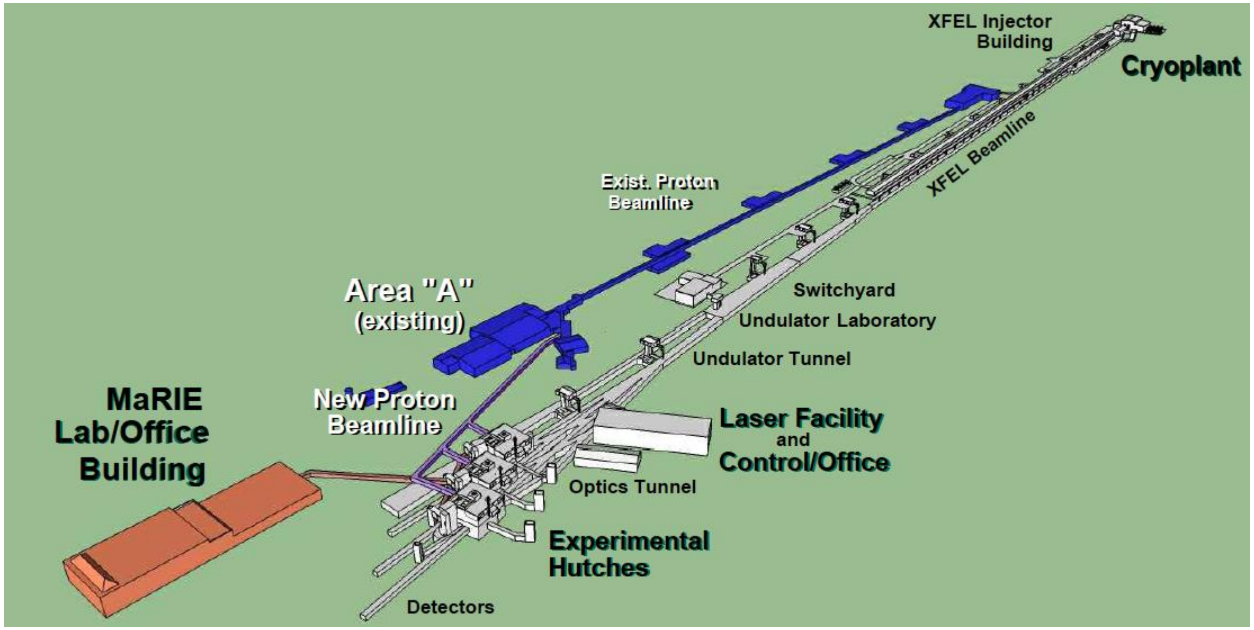
Outline

- MaRIE X-ray FEL
- Harmonic Seeding Concepts
- RAFEL / Fresh Slice Harmonic Seeding
- Numerical Simulations
- Summary

MaRIE XFEL Pre-Conceptual Design





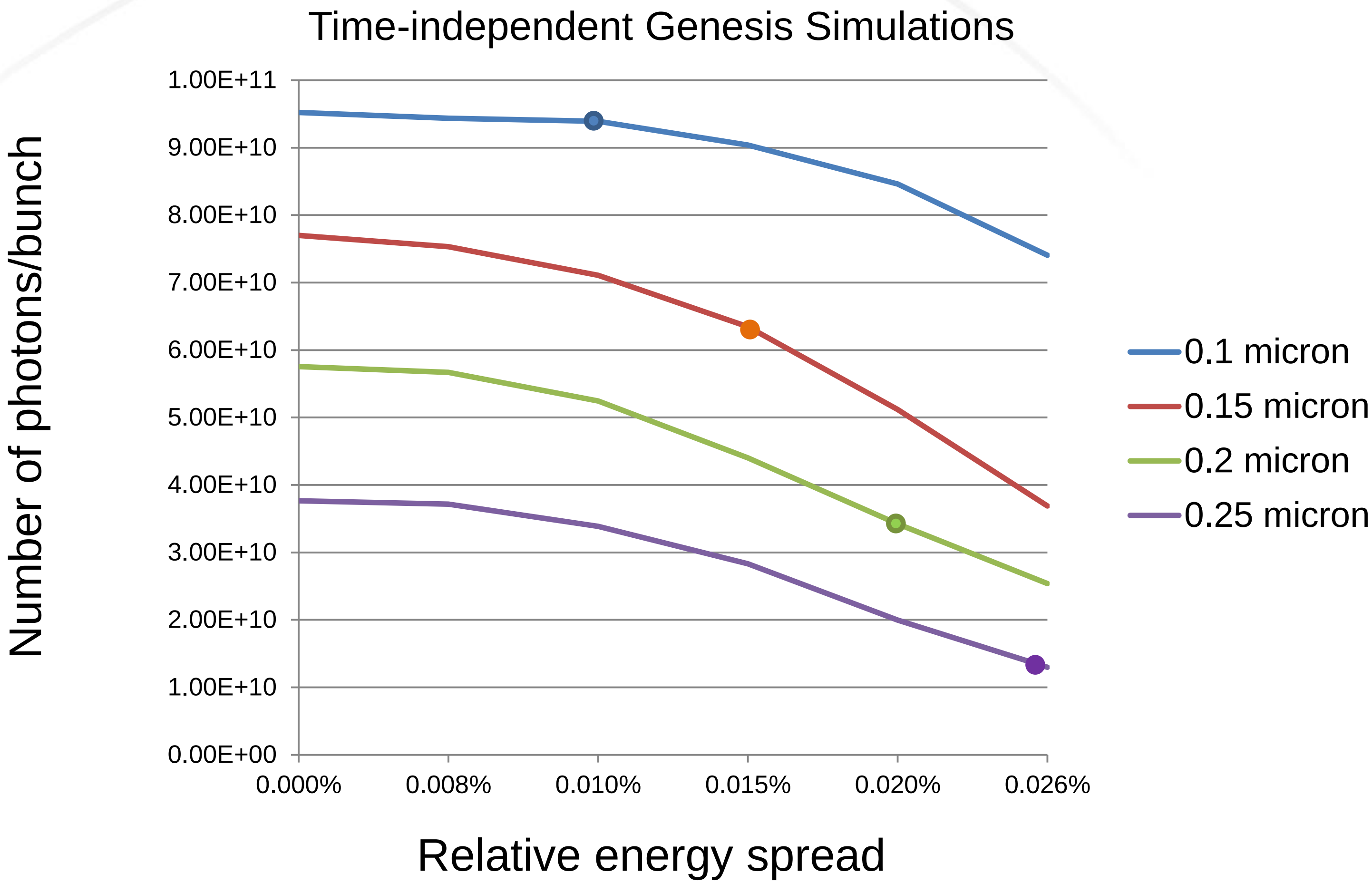
MaRIE Project Overview
R.L. Sheffield et al.
FEL2017 Conference MOD6

MaRIE XFEL Photon & Electron Parameters

	Unit	MaRIE XFEL
Wavelength	Å	0.295
Beam energy	GeV	12.0
Bunch charge	pC	100
Pulse length (FWHM)	fs	29
Peak current	kA	3.5
Normalized rms emittance	μm	0.2
Energy spread	%	0.01
Undulator period	cm	1.86
Peak magnetic field	T	0.70
Undulator parameter, a_w		0.86
FEL parameter, ρ		5×10^{-4}
Saturation length	m	60
Peak power 1D (3D)	GW	24 (12)
Pulse energy	mJ	0.35
# of photons at fundamental		5×10^{10}

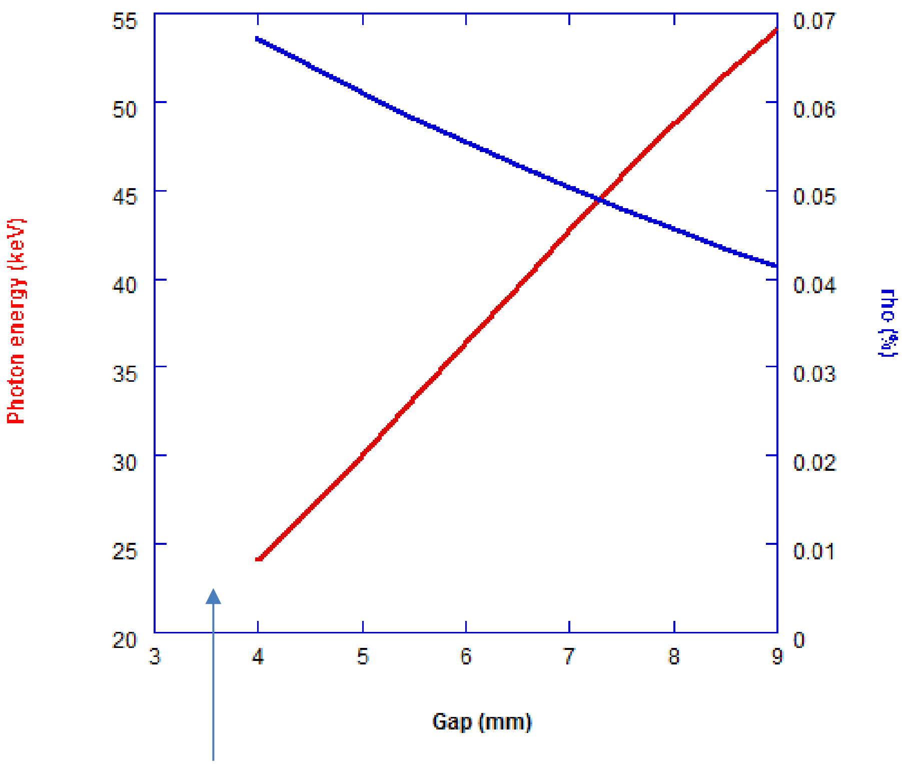
Updated table from B.E. Carlsten, MaRIE XFEL, FLS 2012

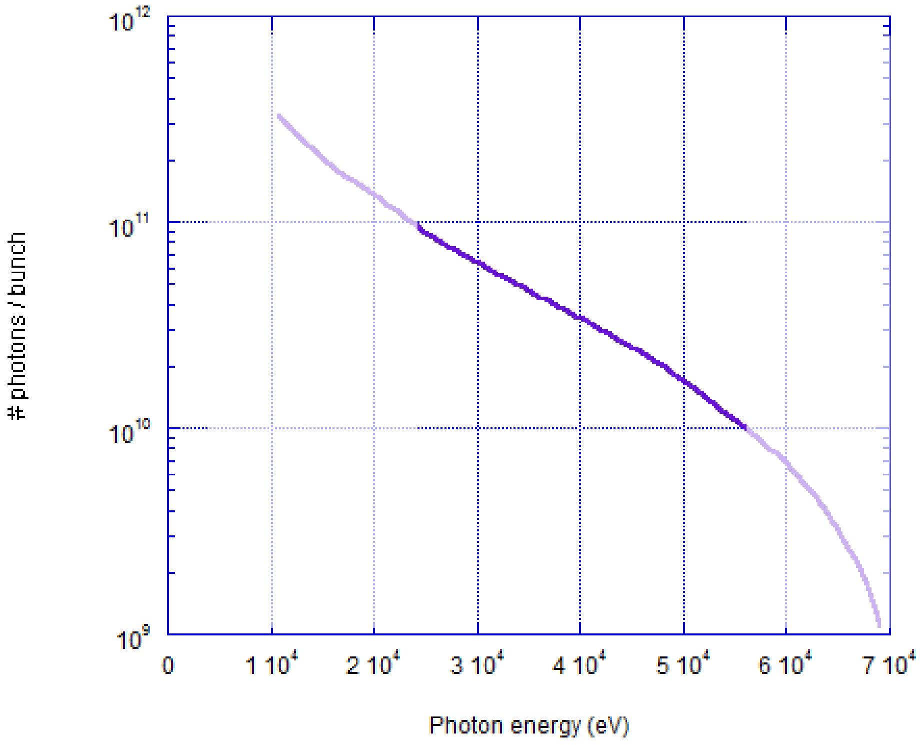
MaRIE XFEL Performance at 42 keV



Variable-gap Short-Period Undulator (SPU)

MaRIE XFEL photon energy tuning range with 12-GeV electron beams (fixed) and varying the gap of the 1.86-cm-period undulator (SPU).





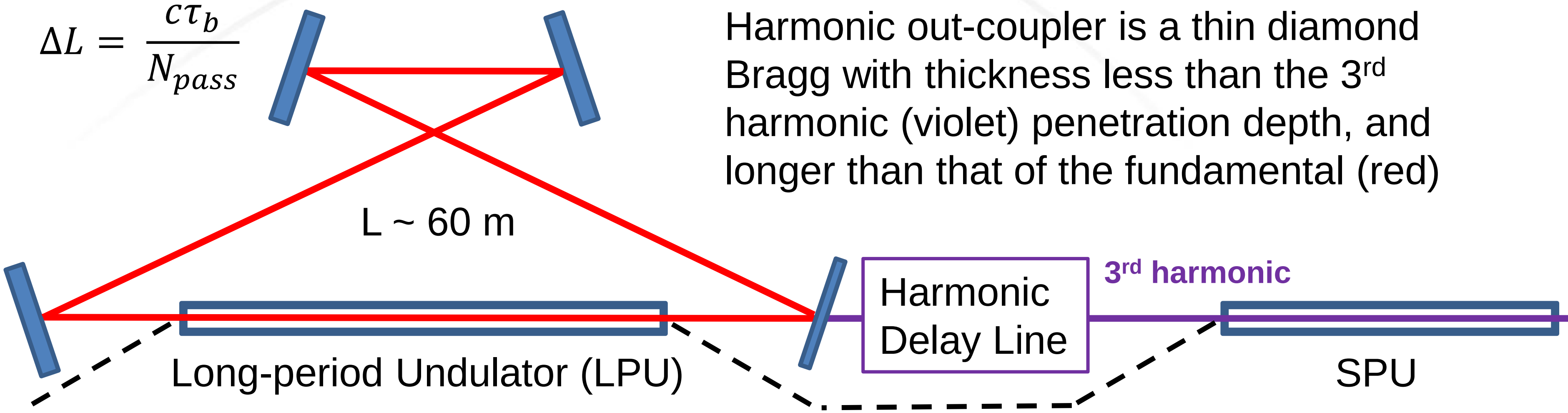
Smallest gap may be <4 mm depending on wakefield calculations

Harmonic Generation and Lasing Concepts

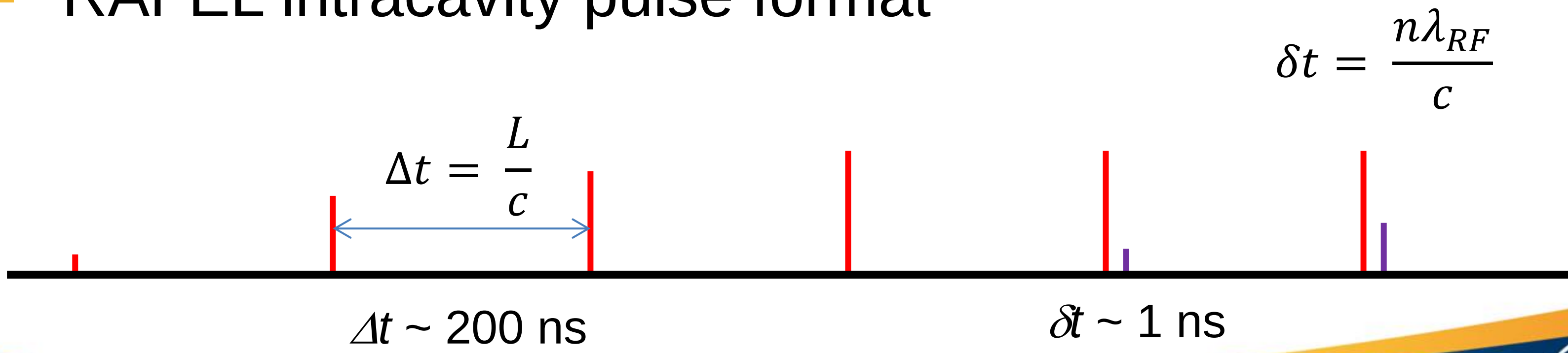
- High-gain harmonic generation, HGHG (Yu et al., 2000 & 2003)
  - Fresh-bunch HGHG cascade (Allaria et al., 2013)
- Higher-order HG & superradiance in seeded FELs (Giannessi et al., 2012)
- Harmonic lasing in FEL amplifier (McNeil et al., 2006)
- Self-seeded harmonic lasing (Schneidmiller et al., 2012 & 2016)
- Harmonic lasing in XFELO (Dai et al., 2012)
- XFELO and harmonic MOPA (Kim et al., 2017)

RAFEL Harmonic Seeding Scheme

Harmonic out-coupler is a thin diamond Bragg with thickness less than the 3rd harmonic (violet) penetration depth, and longer than that of the fundamental (red)

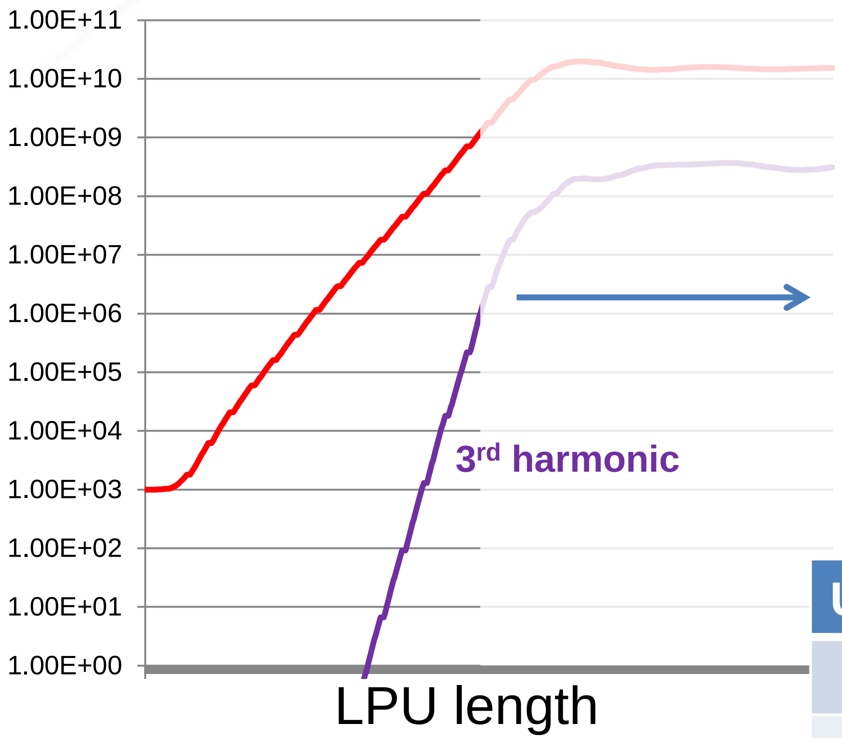


- RAFEL intracavity pulse format

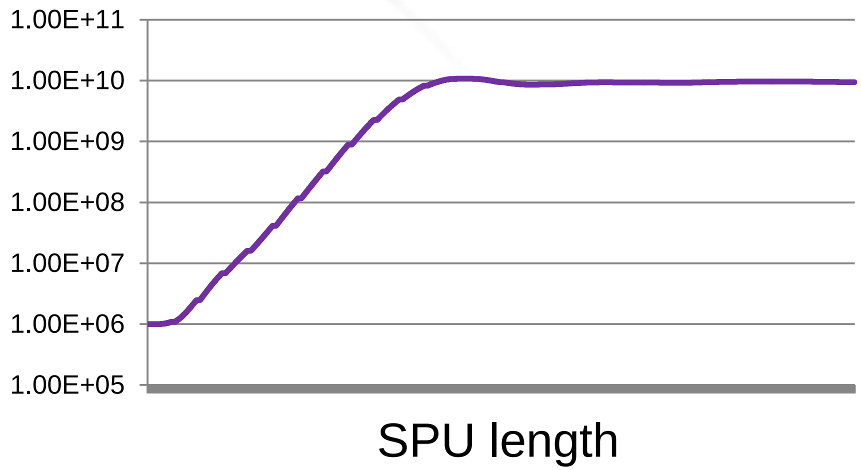


Single-pass Harmonic Seeding Concept

LPU produces the 3rd harmonic via coherent harmonic generation



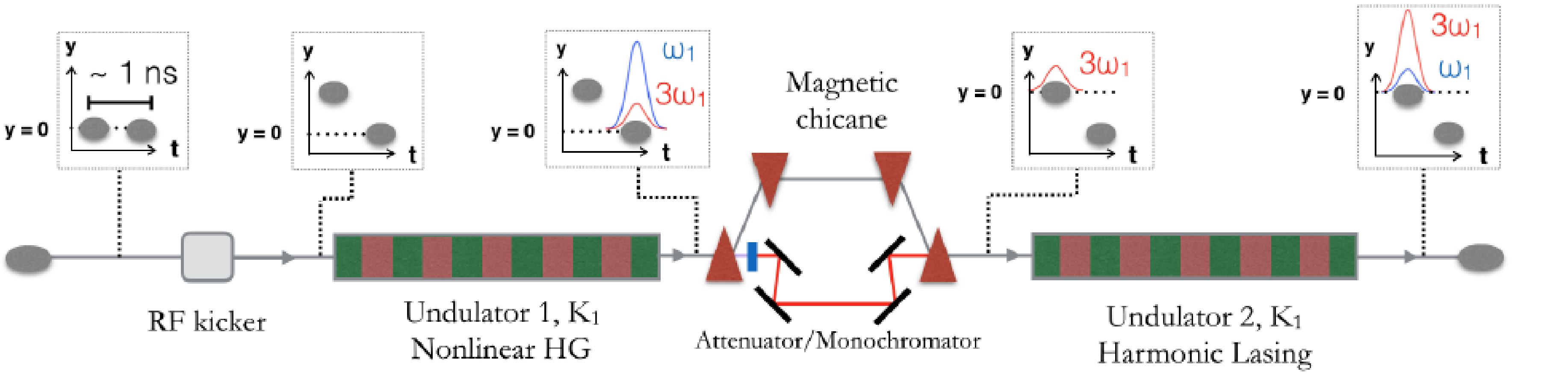
The second stage SPU amplifies the coherent seed as its fundamental



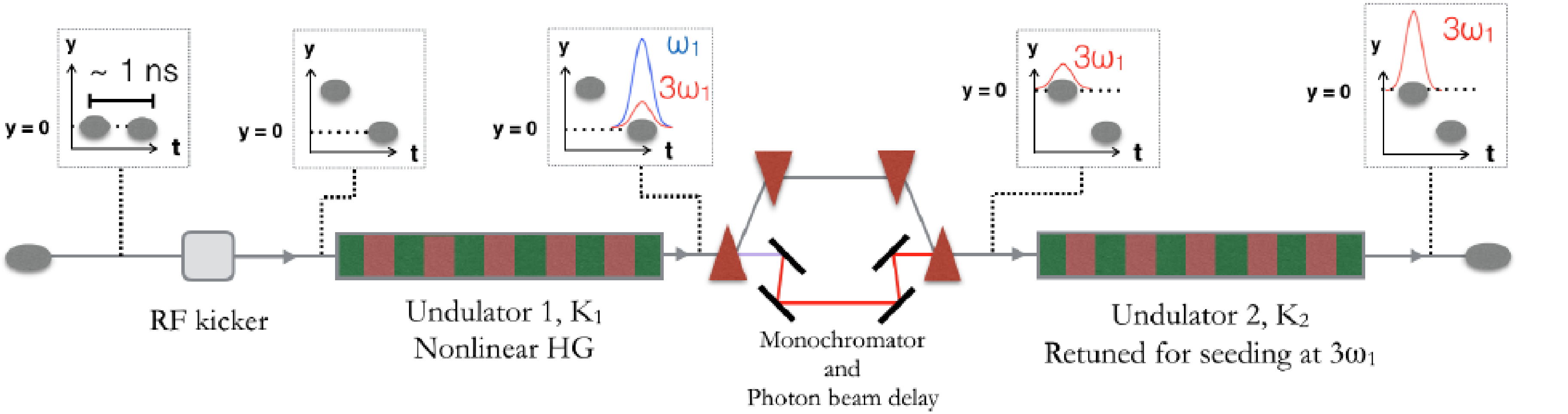
Undulator	Period	K_{rms}	λ_0
LPU	3 cm	1.50	0.885 Å
SPU	1.86 cm	0.86	0.295 Å

Time-independent Genesis simulations

Double-bunch harmonic lasing

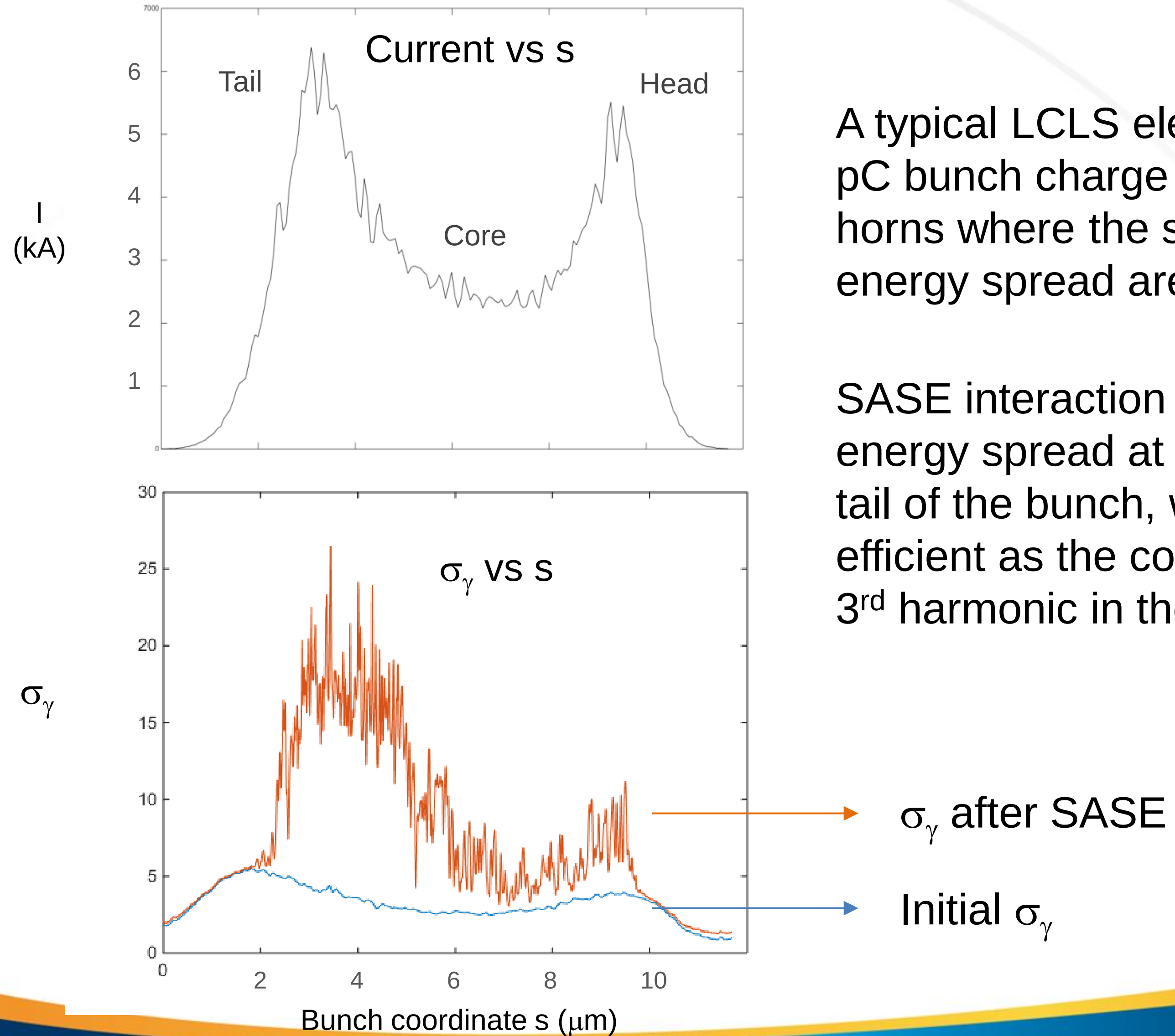


Double-bunch harmonic seeding



C. Emma *et al*., Phys. Rev. Accel. Beams 20 (2017) 030701

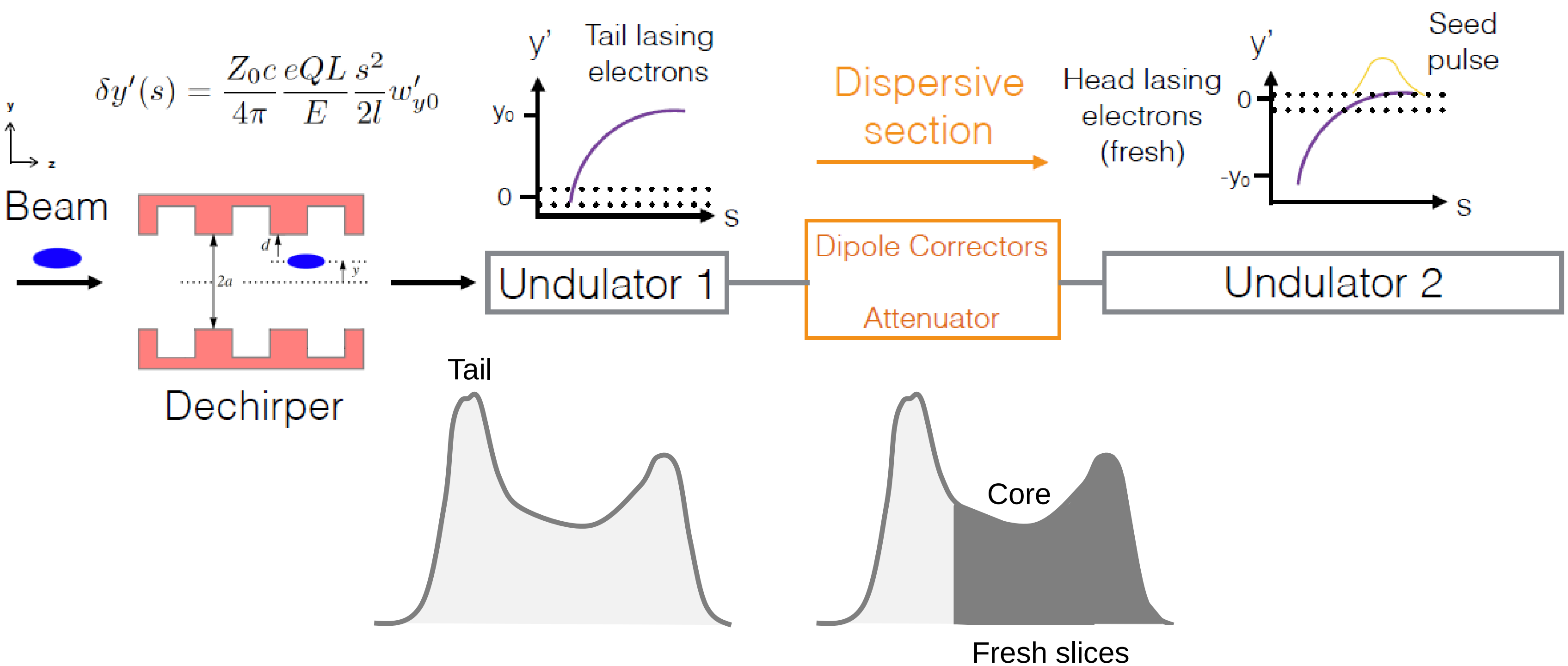
Single-bunch Harmonic Seeding



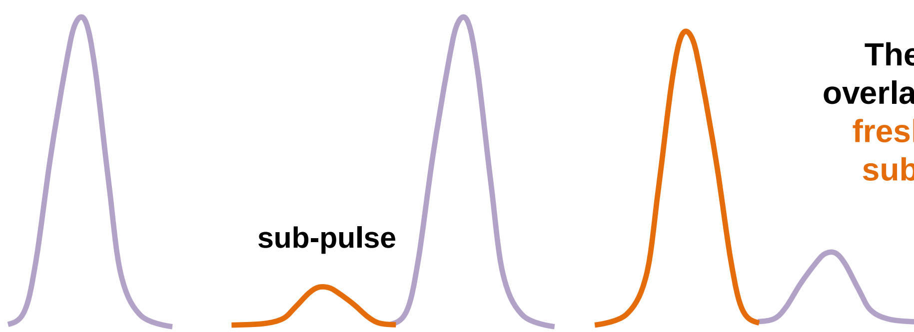
A typical LCLS electron bunch with 185 pC bunch charge has high-current horns where the slice emittance and energy spread are larger than the core.

SASE interaction induces additional energy spread at both the head and tail of the bunch, which are not as efficient as the core in amplifying the 3rd harmonic in the second stage.

Fresh-slice Self-seeding using Dechirper



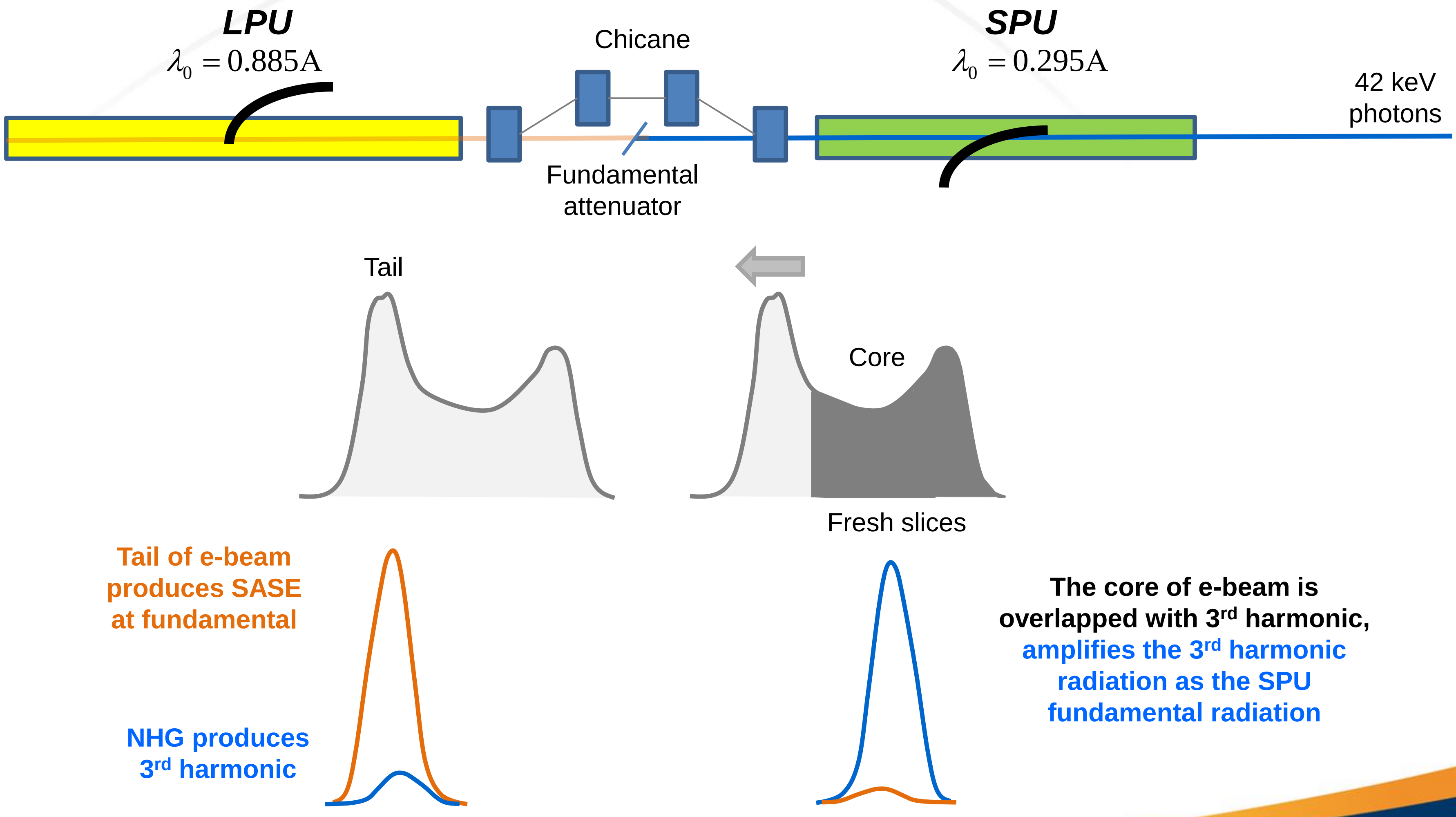
The tail of e-beam produces SASE at the fundamental; monochromatized to produce a coherent sub-pulse



The core of e-beam is overlapped with sub-pulse, fresh slices amplify the sub-pulse in 2nd stage

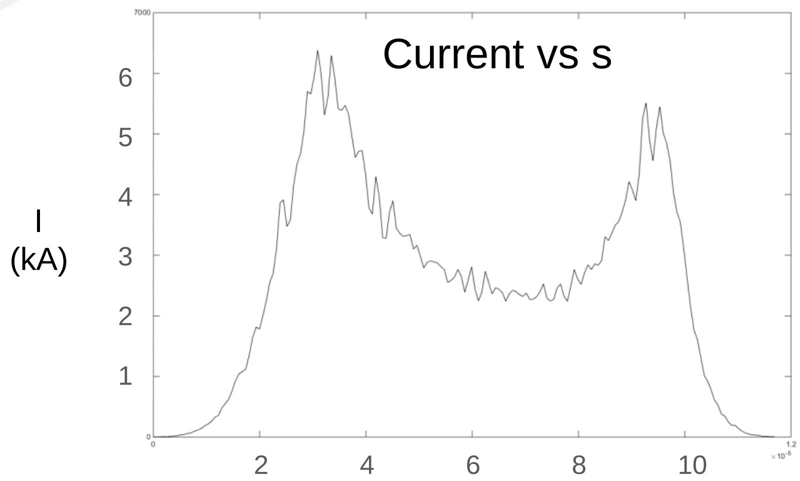
C. Emma *et al*., Appl. Phys. Lett., **110**(15) , 154101 (2017)

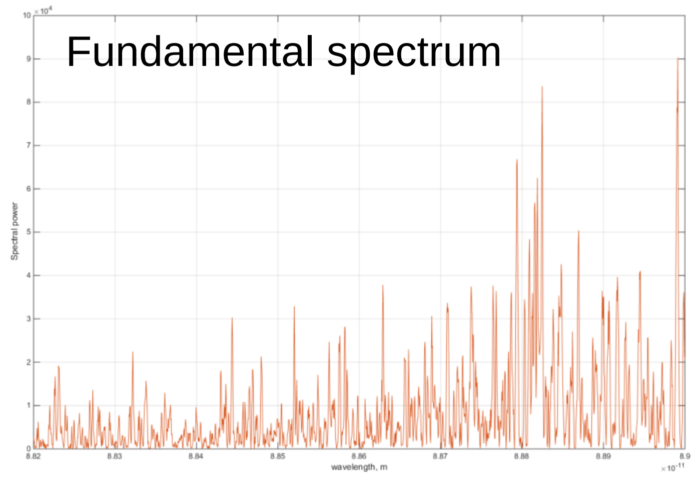
Fresh-Slice Harmonic Seeding

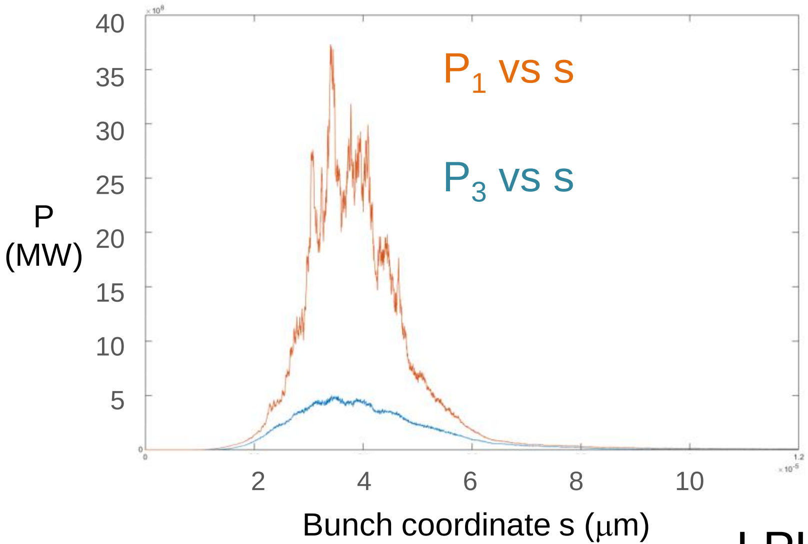


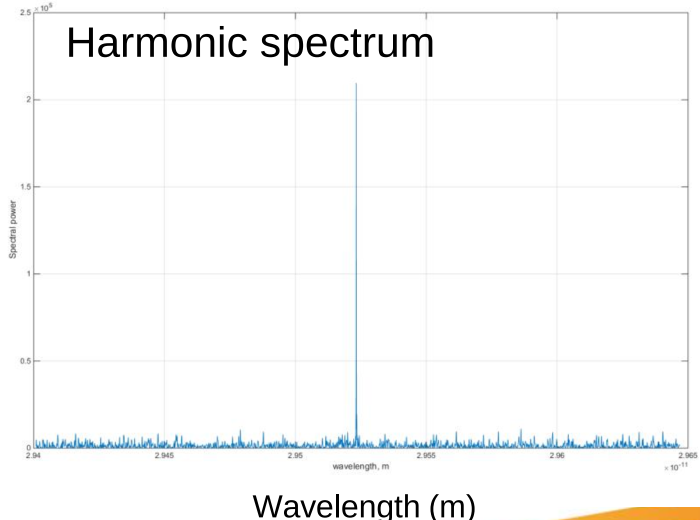
The core of e-beam is overlapped with 3rd harmonic, amplifies the 3rd harmonic radiation as the SPU fundamental radiation

Time-dependent Genesis Simulations - LPU





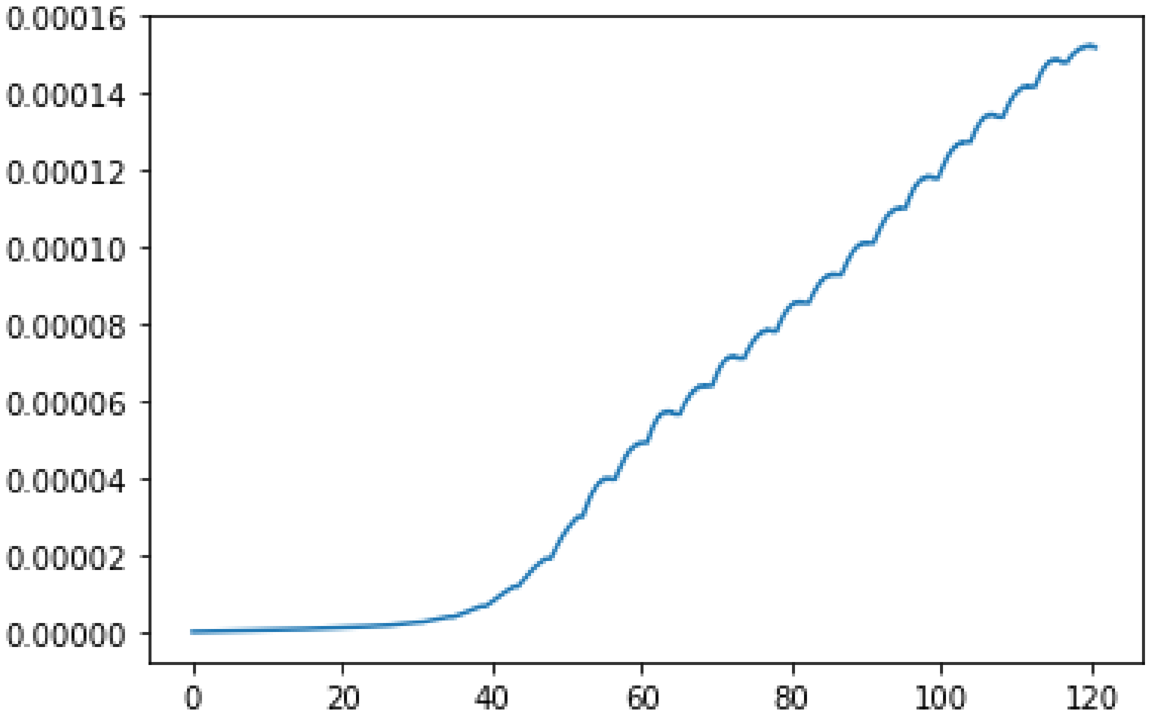




LPU length = 60 m

Time-dependent Genesis Simulations - SPU

Pulse energy at 42 keV (J)



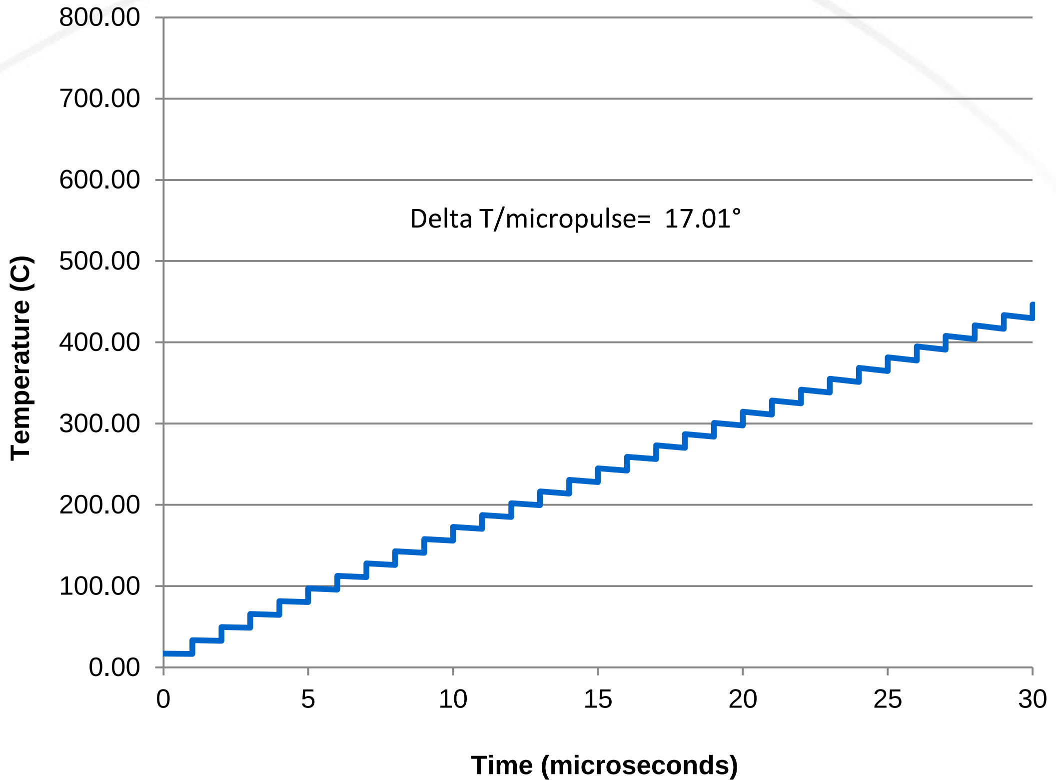
SPU length (m)

The 0.5-μm slice emittance of the LCLS electron beam used in these simulations increases the saturation length to >120 m.

Summary

- Regenerative Amplifier FEL harmonic seeding is being explored to generate both the fundamental at 14 keV and the 3^{rd} harmonic at 42 keV for the MaRIE XFEL.
- Double-bunch and fresh-slice harmonic seeding techniques mitigate the SASE-induced energy spread problem.
- Preliminary simulations show the feasibility of using the 3^{rd} harmonic to seed the fundamental of the second undulator.

Temperature Rise in Sapphire (mp = 2050°C)



Temperature rise after thirty 14-keV X-ray pulses – each having 1.1×10^{11} photons incident on 2-mm sapphire and 100-µm FWHM.